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SOCIETY OF FLORIDA

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November 14, 15 and 16, 1961

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Retiring Officers Listed on Page 308

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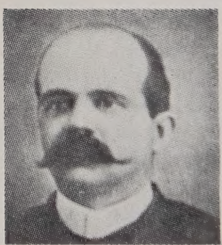
in the Society during his visit. However, he insisted upon returning to Georgia when the meetings were over.

Again the gratitude of the Society is expressed to Cooper Morcock and his good Company for a coffee-break midway of one of the more strenuous sessions and to Dr. I. M. Wofford and his associates in the cause of Nitrogen for a similar break at another session. Both occasions were so conveniently and cleverly arranged by the hotel staff that very little time was lost to the meeting involved and the courtesy was greatly appreciated by all present.

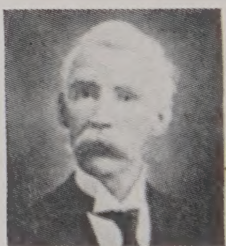
DEDICATION

FLORIDA'S

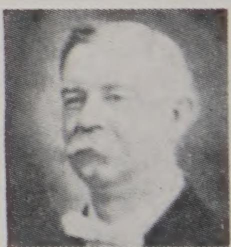
COMMISSIONERS OF AGRICULTURE AND DATES OF OFFICE



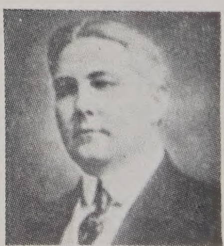
L. B. WOMBWELL
December 31, 1888
December 28, 1900



B. E. McLIN
January 9, 1901
January 31, 1912



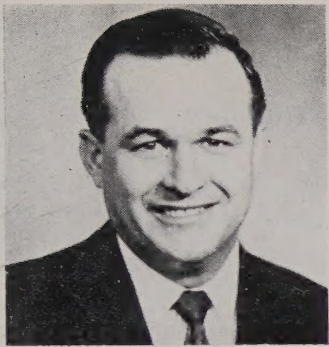
J. C. LUNING
February 5, 1912
February 19, 1912



W. A. McRAE
March 1, 1912
October 31, 1923

NATHAN MAYO
November 1, 1923
April 14, 1960

LEE THOMPSON
April 18, 1960
January 2, 1961



DOYLE CONNER

Commissioner of Agriculture
State of Florida

Doyle Connor was born December 17, 1928 in Starke, Florida. At the age of 12 he took over management of the family farm when his father was called to Camp Blanding on an assignment during World War II and his older brother entered the Air Force. During this period he attended rural school and was active in 4-H work, becoming president of his club.

He also participated in activities of the Future Farmers of America. He served as president of the local F.F.A. chapter and in 1946-47 he became State President. He was elected National President of the F.F.A. in 1948-49.

Shortly after World War II, Doyle flew to Washington, D.C. to broadcast over the "Voice of America" to the Soviet satellite countries, telling them of the opportunities in a free Democracy. He was selected by the Florida Jaycees, in 1950, as one of the five outstanding men in Florida, the youngest ever to receive the award.

After graduation from Bradford County High School in 1947, he entered the University of Florida. He received his Bachelor of Science Degree in Agriculture in 1952. At the University, he was president of the Agriculture Club, and a member of Florida Blue Key, and Alpha Gamma Rho.

In 1950, while still a sophomore, he ran for and was elected to the House of Representatives from Bradford County although just 21 years old. He was elected to a second term while still a student. At 23, he became Chairman of the Agriculture Committee of the House, a post he held for two terms.

In 1955 he was elected Speaker of the House and served in that position in the 1957 Legislature. He was the youngest Representative ever selected to this post. He was selected by his colleagues in the Legislature as one of the three most valuable members of the 1957 session. In 1958 he was chosen as the outstanding farmer in Bradford County by the Jaycees.

Conner is a general farmer. He raises purebred Angus cattle in addition to his commercial herd and has developed a successful insurance and real estate business. He is active in the Florida Farm Bureau, Florida Cattlemen's Association, Masonic Order and the Shrine, Elks, Moose, the State Chamber of Commerce and the Jaycees. He is a Baptist.

He was elected Commissioner of Agriculture November 8, 1960 and was inaugurated as Commissioner of Agriculture on January 3, 1961. He was named one of the Ten Outstanding Young Men in the Nation by the U. S. Junior Chamber of Commerce, January 5, 1961.

Doyle married the former Johnnie Bennett of Marianna, Florida in 1953. They have two sons, Doyle, Jr., John Bryant, and a daughter, Kimberly Ann. They live in Tallahassee at 2902 Woodside Drive.

In October of this year he was elected to the Executive Committee of the National Association of State Departments of Agriculture representing the 13 southern states.

HONORARY LIFETIME MEMBERS 1961

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Dr. J. R. Neller, Agricultural Experiment Station, Gainesville, Florida

Dr. Wilson Popenoe, Calle de la Nobleza num. 2, Antigua, Guatemala, C. A.

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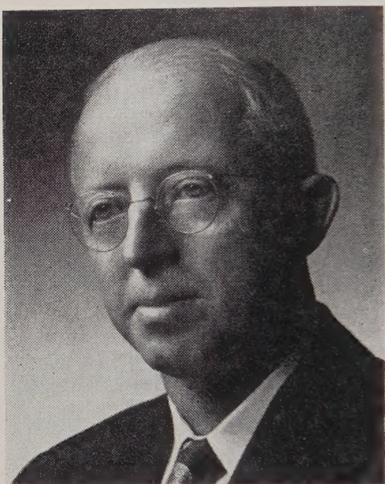

JOSEPH R. NELLER

Soil Chemistry

(Florida)

Joseph R. Neller was born in Ashby, Minnesota, November 13, 1891. He graduated from Macalester College in 1913, received the M.S. degree from the University of Minnesota, in 1916 and the Ph.D. in 1920 from Rutgers. He served from Cpl. to 1st Sgt. U.S.A.F. 1918-19. In 1957 he was awarded an Honorary D.Sc. degree by Macalester College.

Dr. Neller has served as research chemist for the Texas Company, associate chemist at the Washington Agricultural Experiment Station, and soil chemist at the University of Florida Experiment Station from 1937 to date. He served as Chemist in Charge, Everglades Experiment Station at Belle Glade from 1937-44 when he transferred to the Main Station at Gainesville where he has continued his work as Soil Chemist.

Dr. Neller is a charter member of the Soil and Crop Science Society of Florida and served as its fourth president in 1942. He is a fellow of the American Society of Agronomy and a member of many other organizations and Societies including AAAS. He has more than seventy publications to his credit, including bulletins and scientific articles.

In the course of his extensive studies in soil chemistry Dr. Neller developed an injection method for the field application of nematocides and later for anhydrous ammonia. His studies of peat soil losses by oxidation under carefully controlled water table conditions showed the rate of loss essentially to be a straight line function of depth to the water table in the soil. He also did much work with sulfur as an essential element and showed that high phosphate applications to citrus trees produces copper deficiency in the leaves and fruit of the tree as confirmed by analysis of those parts which showed low copper content.

HOWARD E. MIDDLETON

Soil Physics

(Florida)

Howard E. Middleton was born on a farm near Lohrville, Iowa, September 20, 1894. He received his B.S. degree in 1916 from Iowa State and the M.S. degree from the same institution in 1918. His Ph.D. degree in 1924, with a major in soil physics was from the American University in Washington, D. C.

Most of Dr. Middleton's professional career was spent in the U. S. Department of Agriculture, running the entire gamut from Junior Engineer to Principal Soil Conservationist. One of his first assignments in the Department was in the mechanical analysis of soils in the old Bureau of Soils under Professor Milton Whitney. It soon became apparent to him that the standard method used by the Bureau did not obtain complete dispersion of the silt and clay in some particular types of soil. About this time he became acquainted with H. H. Bennett who was just beginning his crusade against soil erosion. Bennett provided him with samples of highly erodible soils as well as samples of soils more resistant to erosion. From these it was comparatively easy to determine that the soils most difficult to disperse were the ones most resistant to erosion. This was the basis of many different tests devised by many workers to measure erodibility of soils and to determine the effectiveness of erosion control practices. With the development of the Soil Conservation Service in the Department of Agriculture he was shifted more and more into administrative work but managed never to lose interest in the technical problems on the ground.

Before retiring in 1957 Dr. Middleton spent two years in Brazil as Agricultural Research Advisor with the U. S. Operations Mission where he strongly urged the application of sound research principles to the improvement of quality in the coffee produced in Brazil.

During his professional career Dr. Middleton has belonged to many technical and professional societies. The membership of which he is most proud, however, is that of being a charter member of the Soil and Crop Science Society of Florida. Before his retirement it was never found possible to attend the meetings of the Society. Since retiring and moving to Florida, however, he has had the pleasure of attending three and is finding much real pleasure in associating with a group of scientists dedicated to the further development of a natural science to which he has already devoted a full lifetime of highly productive effort.

CONTRIBUTED PAPERS (SOILS)

David W. Jones, *Presiding*

A Short Quantitative Method for Estimating the Population Density of Soil Fungi[1]

N. C. SCHENCK AND E. A. CURL[2]

The dilution-plate method is the one most commonly used to estimate the numbers of fungus growth units in soil. This method, as presently used (1), requires considerable glassware, large quantities of sterile water, a mechanical shaker, and approximately 45 minutes to process one sample. As a result, this method is burdensome when a large number of samples must be processed.

Several other methods for isolating soil fungi are listed by Johnson *et al.* (1), but these are primarily useful in ecological studies of soil fungi. Recently, new methods have been described and others modified to overcome limitations of older methods. Johnson and Manka (2) modified Warcup's soil-plate method (4) by diluting soil samples with sterile sand prior to plating, thus adapting this method for use with soils densely populated with fungi. Watson (5) increased the reliability but also the complexity of the dilution-plate method by washing the soil and removing excessive numbers of spores of *Penicillium* and *Aspergillus* prior to plating. Menzies (3) developed an apparatus for continuous dilution of a soil sample under constant agitation. The optimum dilution for colony counts can be determined readily by this method, but the effect of constant dilution on recovery of various fungus species has not been determined.

Other studies by the senior author in Florida required a simple, rapid method for estimating fungus populations in numerous soil samples. A short method (hereinafter referred to as the dropper method) was devised and studies were conducted to compare this method with the dilution-plate and Warcup's soil-plate method as modified by Johnson and Manka. Results of these studies and a description of the dropper method are reported herein.

MATERIALS AND METHODS

Samples were taken from the upper 3 inches of soil at 3 locations in Alabama. Samples from each location were composited in polyethylene bags and stored at room temperature. Soil types and crops represented were as follows: 1) Susquehanna clay, in grass pasture; 2) Chesterfield sandy loam, in cotton; and 3) Norfolk fine sandy loam, in corn.

In one series of tests the dropper and dilution-plate methods were compared using samples of each soil type at 1, 4 and 9 days after collection. The dilution-plate method was essentially that described by Johnson *et al.*

1Florida Agricultural Experiment Station Journal Series No. 1397.

2Assistant Plant Pathologist, Watermelon and Grape Investigations Laboratory, Leesburg, Florida and Associate Plant Pathologist, Department of Botany and Plant Pathology, Auburn University, Auburn, Alabama, respectively.

The senior author gratefully acknowledges the assistance and cooperation of the staff as well as the use of the facilities in the Department of Botany and Plant Pathology, Auburn University, where this work was performed.

(1). In the dropper method 50 mg. of screened soil (dry-weight basis) were placed into each of 3 screw-cap bottles of 1-ounce capacity containing 25 ml. of sterile, demineralized water. Each water-soil mixture was shaken vigorously by hand for 15 seconds and further agitated by forcing the mixture in and out of a sterile medicine dropper for 5 seconds. Two drops (approximately 0.1 ml.) of the mixture from each bottle were placed into each of 5 Petri dishes; 15 ml. of peptone-dextrose agar with rose bengal and streptomycin were added and swirled gently to disperse the soil particles. A soil-water dilution of 1:5000 was used with both methods.

Another experiment compared the dropper, dilution-plate and modified Warcup's soil-plate methods for estimating fungus populations in Norfolk fine sandy loam soil. The modified Warcup's soil-plate method was essentially that described by Johnson and Manka (2). One-gram samples of screened soil (dry-weight basis) were diluted with screened, sterile sand to make soil-sand ratios of 1:1, 1:5, 1:25, and 1:100. The portions of soil and sand were thoroughly mixed by shaking in flasks for one minute: then approximately 2.7 mg. were transferred with a microspatula to each Petri dish. As in the other methods, peptone-dextrose agar with rose bengal and streptomycin was added to the plates.

All plates were incubated at 25°C. Numbers of fungus colonies were recorded after 5 days, and fungi were identified after 7-14 days.

RESULTS

There were a few more colonies and species of fungi recovered from 3 Alabama soils by the dilution-plate method than by the dropper method (Table 1). Although soil fungus populations varied significantly among the 3 soil types and after various durations of storage of the soil samples, there was no significant difference between the methods in the estimates of such populations (Table 2). A further indication of the reliability of the dropper method was the lack of significant interaction within the range of soil types and storage periods in this test (Table 2). There was less variation in number of colonies per plate with the dilution-plate method

TABLE 1.—NUMBERS OF FUNGUS COLONIES AND SPECIES IN 3 ALABAMA SOILS AS DETERMINED BY THE DROPPER AND DILUTION-PLATE METHODS.

Soil type	Storage period[1]	Dropper		Dilution-plate	
		Species	Colonies per 0.2 mg. of soil	Species	Colonies per 0.2 mg. of soil
Susquehanna	1	12	37.7	18	42.2
Chesterfield	1	21	24.7	25	43.4
Norfolk	1	20	27.1	16	10.4
Susquehanna	4	12	94.7	19	95.9
Chesterfield	4	19	64.7	23	47.9
Norfolk	4	17	30.3	18	26.7
Susquehanna	9	20	42.4	20	107.1
Chesterfield	9	27	82.9	26	49.4
Norfolk	9	15	37.3	25	50.4
	Mean	18.2	49.1	21.2	52.6

[1]Days in storage in polyethylene bags prior to testing.

TABLE 2.—MEAN SQUARES FOR NUMBERS OF FUNGUS COLONIES IN 3 ALABAMA SOILS AS DETERMINED BY 2 METHODS.

Source	d.f.	Mean square
Storage periods	2	145.20*
Soils	2	178.04**
Methods	1	1.92
Soils x Methods	2	26.24
Error (a)	10	21.62
Replications (Soils and methods)	36	2.12
Plate replications	216	0.38
Total	269	

*Significant at the 5% level.
**Significant at the 1% level.

(SD = 17.78) than with the dropper method (SD = 31.22), but the difference in variation was not significant (P = 0.25).

The fungi identified in 5 randomly selected plates for each soil type and method (using soil stored 9 days in polyethylene bags) are listed in Table 3. Of 52 fungi identified to genus or species, 38 were recovered by both dropper and dilution-plate methods. Other species were isolated by only one of the methods. The species most frequently isolated were the same by either method: *Mucor christianiensis* from Susquehanna clay; *Cladosporium* sp. from Chesterfield sandy loam; and *M. christianiensis* and *Penicillium janthinellum* from Norfolk fine sandy loam. Nine species were recovered from all 3 soil types. Of these, *M. christianiensis, P. janthinellum*, and *Aspergillus terreus* were recovered by both methods.

In a comparison of dropper, dilution-plate, and modified Warcup's soil-plate methods, the mean number of colonies recovered per plate was nearly the same for each method (Table 4). Most variation occurred in the modified Warcup's method and least variation in the dilution-plate method, but differences were not statistically significant. A 1:1 soil-sand dilution gave an adequate number of colonies per plate with the modified Warcup's method, but dilutions of 1:5, 1:25, and 1:100 resulted in plate counts too low for accurate population estimates in all 3 soil types. The number of species of fungi isolated by the modified Warcup's method (data not shown) was approximately equal to that of the other methods.

DISCUSSION

The dropper method and the modified Warcup's soil-plate method of Johnson and Manka are considerably shorter and simpler than the conventional dilution-plate method. Although the shorter methods utilize very small quantities of a soil sample, they seem to provide a representation of numbers and kinds of soil fungi comparable to those obtained by the dilution-plate. Besides rapid determination of fungus populations in large numbers of soil samples, these short methods may be used advantageously for studies on fungus populations in limited areas of soil such as the rhizosphere of roots.

Subsequent to the studies reported in this paper, the senior author has successfully applied the dropper method to field studies in Florida to determine effects of various soil fumigants on fungus populations.

TABLE 3.—RELATIVE INCIDENCE OF FUNGUS SPECIES IN 3 ALABAMA SOILS AS DETERMINED BY DROPPER AND DILUTION-PLATE METHODS.[1]

Species	Susquehanna		Chesterfield		Norfolk	
	Dilution-plate	Dropper	Dilution-plate	Dropper	Dilution-plate	Dropper
Phycomycetes						
Cuninghamella bertholletiae Stad.	1	1	1			
Cuninghamella echinulata Thax.	1	1	1			
Mucor christianiensis Hagem	176	163	3	1	28	9
Mucor sp.				1	1	
Rhizopus nigricans Ehren.			1			
Zygorhynchus sp.	11	5				
Phythiopsis cymosa de Bary					1	
Ascomycetes						
Neocosmospora vasinfecta E.F.Sm.			1	2		
Chaetomium globosum Kunze		1				
Fungi Imperfecti						
Aspergillus candidus Link	2					
Aspergillus flavus Link				1		
Aspergillus fumigatus Fres.			2	2	9	1
Aspergillus nidulans (Eidam) Wint.				1	2	2
Aspergillus rugulosus Th. and Rap.			1	2	1	
Aspergillus terreus Thom	25	11	8	22	10	5
Aspergillus ustus (Bain.) Th. and Ch.					3	2
Penicillium canescens Sapp	2	1		3	5	6
Penicillium cyaneum (B. and S.) Biour.			9	2		
Penicillium commune Thom		1				
Penicillium decumbens Thom	1					
Penicillium fellutanum Biour.		1		3	2	4
Penicillium fuscum (Sapp) Thom					1	
Penicillium herquei Bain. and Sar.	1					1
Penicillium janthinellum Biour.	10	13	4	2	14	20
Penicillium lilacinum Thom			1	2	8	2
Penicillium nigricans Bain.					4	
Penicillium notatum West.	4	1	2		5	6
Penicillium oxalicum Thom		1			1	
Penicillium purpurogenum Stall.	2			1		
Penicillium restrictum Gil. and Abb.	2			2		1
Penicillium spinulosum Thom	1	1				
Penicillium verruculosum Pey.			1	1		
Alternaria tenuis Nees			1	1		
Alternaria grisea Szilvinyi			1	1		
Cephalosporium acremonium Corda			1			
Cephalosporium coremoides Rail.					1	
Cephalosporium roseo-griseum Sak.	2		4	1		
Cephalosporium sp.	1	1				
Cladosporium sp.			92	128	1	
Curvularia geniculata (T. and E.) Boed.	2	1				
Fusarium oxysporum (Schl.) Syn. and Han.		1		1	2	
Fusarium roseum (Lk.) Syn. and Han.			2	2		
Fusarium solani (Mart.) Sny. and Han.					1	1
Gliocladium catenulatum Gil. and Abb.	4	3	1		1	
Gliomastix sp.			1	3		
Gonatobotryum sp.					1	
Myrothecium sp.		1		1		
Paecilomyces varioti Bain.			1			
Phoma sp.			8	5	1	1
Sepedonium crysospermum (Buil.) Fries	1					
Spicaria violacea Abb.			1			
Trichoderma viride Per. ex Fries	13	13	2	6	1	
Unknown sp.		3	3	1	1	1

[1]Number of colonies on 5 randomly selected plates from soil stored 9 days in polyethylene bags.

TABLE 4.—COMPARATIVE ESTIMATES OF THE FUNGUS POPULATION IN NORFOLK FINE SANDY LOAM AS DETERMINED BY 3 METHODS.

Method	Number of fungus colonies per 0.2 mg. of soil	
	Mean	Range
Modified Warcup[1]	29	15-52
Dropper	28	18-41
Dilution-plate	30	21-39

[1]Soil-sand ratio = 1:1

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Attempts at Controlling Citrus Burrowing Nematodes Using Nematode-Trapping Fungi[1]

A. C. TARJAN[2]

Plant nematology, although of close kinship to plant pathology because nematodes can cause plant diseases, also receives guidance from plant entomology. This is justifiable since both nematodes and insects are animals and, in many cases, problems involving biology, ecology, systematics, and control are similarly solved in both fields. Hence it is only logical that as the economic plant nematologist seeks ways to control noxious nematodes, he considers a method of control that has enjoyed some success in entomology, viz., biological control.

Biological control can be defined as the introduction, encouragement, and artificial increase of predaceous and parasitic insects, other animals, and diseases (34). Perhaps the classical example of biological control is the introduction in California in 1888 of the Australian lady or vedalia beetle (*Rodolia cardinalis* Muls.) to destroy cottony cushion scale (*Icerya purchasi* Mask.) of citrus. This pest, which threatened to destroy the citrus industry, was brought under control within two years (2). Unfortunately, the success of this control was subsequently destroyed by promiscuous applications of DDT which killed the vedalia and permitted the re-emergence of cottony cushion scale in heavy and destructive infestations such as had not occurred for more than half a century (3). Yet, in many cases, the concept of biological control is being successfully applied;

[1]Florida Agricultural Experiment Stations Journal Series No. 1419.
[2]Nematologist, Florida Citrus Experiment Station, Lake Alfred.

presently there are more than 95 introduced parasites and predators of insect pests established in the continental United States (21).

Nematodes fall easy prey to a number of organisms, among which are protozoans, bacteria, other nematodes, and fungi (9). Of these, fungi appear to offer greatest promise as agents of biological control (13). The peculiar predaceous habit of one of the most ubiquitous of these forms was first noted in 1876 (40). In 1888, Zopf (50) investigated the mode of action of *Arthrobotrys oligospora* Fres. against the wheat nematode and speculated on the possibility of this fungus being antagonistic to the golden nematode of potatoes. Linford & Oliveira (25, 26) found that numerous predatory fungi were present in Hawaiian fields and suggested that green manures stimulated predaceous activity of these forms. Linford, Yap, & Oliveira (28) obtained highly significant reductions of root-knot injury when large amounts of organic matter were added to soil. In the concluding paper of this series, Linford & Yap (27) found that none of the fungi used entirely restricted nematode growth and that these predaceous forms differed in their abilities in soil to restrict nematode injury in susceptible plants.

Several French workers conducted a series of tests with nematophagous fungi, some of their attempts at control being directed to nematode parasites of plants. Deschiens (4) showed that nematode parasites were attacked by certain nematophagous fungi. In working with root-knot nematodes affecting begonias, Deschiens, Lamy, & Vautrin (5) used certain nematode-trapping fungi and were able to reduce the number of plants becoming infected and, perhaps more important, reduce the amount of infection in treatments as compared to controls.

The greatest stimulus to this concept of fungus control of phytopathogenic nematodes has been furnished by C. L. Duddington of England (10, 11, 12, 13, 14). Russian workers likewise have been active in the field as evidenced by the writings of Soprunov & Soprunova (38) and Gorlenko (19). Soprunov (37) published a 365-page book on the subject, containing many descriptions of new fungi and extensive experimental data. An interesting application of nematode-trapping fungi in controlling human hookworm was described by Soprunov & Tendetnik (39), who spectacularly controlled the disease among miners by disbursing conidia of *Arthrobotrys dolioformis* Sopr. and *A. oligospora* Fres. at rates of 50 to 100 g per m^2 in an infested coal mine five times in three years. Biological control of nematodes has received further support in recent years from Scognamiglio (36), who discusses means of achieving more dependable control; Feder (18), who stresses the need for investigations on ecological aspects of nematode predators; and Duddington (14), who sensibly advocates an objective of crop protection as against complete extermination of nematode pests.

Not all workers have been successful in using fungi for biological control. In working with the fungus *Dactylaria eudermata* Drechs., Hutchinson & Mai (23) concluded that the trapping devices of the fungus did not effectively control the golden nematode, *Heterodera rostochiensis* Wollenweber. Mankau (30, 31) used fungi that, in culture, were efficient nematode trappers but that in the field failed to control root-knot nematodes affecting tomato and okra. He blamed this and other failures in part on the presence of antagonistic microorganisms in soils (32). Tests of similar nature but against cyst nematodes, were conducted by Duddington, et al. (16, 17) without obvious control of the nematode parasites. Hams & Wilkin (20), also working with cyst nematodes, showed that use of nematophagous fungi

in pot tests resulted in sufficient nematode control but that such control was nonapparent in field tests. It was felt by van der Laan (47) that there is little hope in obtaining biological control of plant-parasitic nematodes with the parasites thus far known.

The possibility of biological control of nematodes affecting citrus was proposed by DeWolfe, et al. (6). After applying wood shavings mulch to citrus trees under sprinkler irrigation, they observed *Arthrobotrys* spp. capturing the citrus nematode, *Tylenchulus semipenetrans* (Cobb). It was postulated that irrigation and artificial mulches approximate natural conditions, thus enhancing the activity of nematophagous fungi (7). Mankau & Clarke (33) reported frequent isolations of trapping fungi from citrus groves in Southern California, as did Tarjan (45) from groves in Florida.

Spreading decline of citrus in Florida, caused by *Radopholus similis* (Cobb) Thorne lends itself to investigations on biological control. Although the light, sandy soils in which this malady exists are low in organic matter, numerous nematophagous fungi can be readily isolated. Thus far, attempts at chemically eliminating spreading decline have not been completely successful and it may become necessary to "live with" the nematode. This may be accomplished by practicing biological control to depress the destructiveness of the disease and permit economic returns from infected citrus plantings. An integrated chemical-biological control program for achieving this objective is also worthy of exploration.

Since 1958, a number of experiments have been carried out to investigate the possibility of controlling citrus burrowing nematodes with nematophagous fungi. This work has been conducted in the laboratory, greenhouse, and in nematode-infected citrus groves at the Florida Citrus Experiment Station in Lake Alfred.

MATERIALS AND METHODS

Although experimental procedures generally differed between tests performed, certain techniques were of sufficient utility so as to apply to all tests. Nematode extractions from soil were performed with the aid of a modified Oostenbrink elutriation apparatus (46) whereas root-inhabiting nematodes were isolated by incubation of roots in polyethylene plastic bags for one week at 78 F (42).

Mycological techniques involved the use of a 2% Difco corn meal agar and a temperature of 78 F for the isolation from soil and subsequent growth of fungi. Expression of predaceous habit among isolated fungus colonies was stimulated by the addition of *Panagrellus redivivus* (L.) Goodey to the Petri plates (43).

ORGANIC MATTER STUDIES

The literature abounds with accounts of beneficial effects to plants after addition of organics to soil. Accompanying evidences of reduction of nematode populations, although not as plentiful, are nevertheless encouraging. Stewart, et al. (41) reported fewer nematodes in the roots of sugar cane grown in soil treated with compost, molasses, or sugar cane "filter press mud." Linford & Oliveira (25) observed similar reduction in numbers of root-knot nematodes when green manures were added to soil. Linford, et al. (28) later found that nematode injury was further reduced when dried, rather than fresh, plant material was used. A striking increase in

yield from a lemon grove mulched with wood shavings was noted by DeWolfe, *et al.* (8) who attributed this response to enhanced activity of nematophagous fungi. Duddington, *et al.* (17) added leaf mold, compost, and chopped cabbage leaves to soil with and without inoculum of *Dactylaria thaumasia* Drechs. They found that final populations of the golden nematode on potato roots were not affected by this treatment. From a similar test involving addition of bran and two nematode-trapping fungi to soils containing the sugar beet nematode, *Heterodera schachtii* Schm., they concluded that only the bran caused a significant depression in the beet eelworm population (16). Using a green manure of chopped cabbage leaves, Duddington (15) has twice obtained reductions of cyst nematodes on roots of oat seedlings. Similar reductions of nematodes due to the addition of organic matter have been reported by Johnson (24), Hutchinson, *et al.* (22), and van der Laan (48). The latter author concluded that organic manuring may promote physiological changes in the plant which accordingly develops a slight resistance to nematodes. In direct contrast, Nolte (35) found that addition of compost to land infested with golden nematodes increased the number of nematodes on roots of tomatoes following cropping to potatoes.

In view of the importance attributed to organic matter in stimulating growth of trapping fungi, 28 types of organic material were evaluated as fungus substrates for growth of *Dactylaria thaumasia*. It was found that sugar cane filter press mud, corn bran, soybean mill feed, rotted pecan shells, oat meal, and oat hulls supported good mycelial growth and sporulation (Table 1). Subsequent tests were made adding suspensions containing about 2,500 *Panagrellus redivivus* (as sacrificial animals) to flasks containing some of these organic substrates on which either *Dactylella* sp., *D. ellipsospora* (Preuss) Grove, *Arthrobotrys oligospora*, *A musiformis* Drechs., or *Dactylaria thaumasia* were growing (44). Counts of surviving nematodes after six days indicated oat hulls to be the best organic substrate for stimulating fungal activity and *A. musiformis* to be the most voracious fungus (Table 2).

PREDATION OF RADOPHOLUS SIMILIS BY ARTHROBOTRYS MUSIFORMIS

Although *A. musiformis* has been shown to be an active predator of *P. redivivus*, it was not known whether it would exhibit similar properties against *R. similis*, a smaller nematode. Hence, a number of corn meal agar cultures in which the fungus was growing were furnished with motile burrowing nematodes. Numerous specimens, regardless of size or sex, were trapped and consumed by the fungus, proving that the small size of the nematode was no deterrent to its being snared.

GROWTH OF ARTHROBOTRYS MUSIFORMIS ON COVER CROP AND CITRUS ROOT MATERIAL

The importance of organic additives for enhancing activity of predaceous fungi previously has been reported by a number of authors. Yet, the cost of supplying sufficient amounts of introduced material so as to benefit the fungi seems prohibitive. Florida's citrus groves usually contain luxuriant growth of cover vegetation that, in normal cultivation, is disced

TABLE 1.—GROWTH CHARACTERISTICS OF *Dactylaria thaumasia* ON VARIOUS ORGANIC SUBSTRATES.

Excellent Mycelial Growth and Sporulation	*No Fungus Growth*
Sugar cane filter press mud, corn bran, and shredded peanut hulls	Citrus pulp Fur-Ag Spent hops
Excellent Mycelial Growth—Poor Sporulation	Corn silage
Soybean mill feed	Rice hulls Pea silage
Good Mycelial Growth—Good Sporulation	Tobacco stems
Rotted pecan shells, Vim oat meal, and unground oat hulls	Sugar beet pulp Pecan shell meal Sugar cane bagasse
Fair Mycelial Gowth—Good Sporulation	Pine shavings
Ground oat hulls	Pine saw dust Milk whey powder
Poor Mycelial Growth—No Sporulation	Cotton burr ash
Cellulose gum (CMC), dried sludge, stockyard manure, dried beef blood	Animal tankage Castor pomace

in to provide green manure. If such material were suitable for fungus growth, then costs involved in adding imported organic matter to the soil might be much reduced, if not completely eliminated.

Decaying citrus roots are one of the principal sources of organic matter in groves. DeWolfe, *et al.* (8) claimed that they had isolated nematophagous fungi from citrus roots, although they failed to identify the fungi or to state whether the roots were living or dead. It was deemed necessary, therefore, to investigate the suitability of dead citrus roots as a growth medium for *Arthrobotrys musiformis*.

Representative samples of grove cover crops were collected, dried, and ground in a Wiley mill. One part of organic material and three parts of water were mixed and autoclaved in 15 ml Erlenmyer flasks. Rough lemon feeder roots were likewise treated. After cooling, flasks were inoculated with *A. musiformis*.

After one week the fungus had grown abundantly on the citrus roots. Growth on the cover crop substrates is shown in Table 3.

Vasey grass (*Paspalum urvillei* Steud.) and Natal grass (*Rhynchelytrum*

TABLE 2.—COMPARATIVE EFFECT *of* ORGANIC SUBSTRATE AND FUNGUS SPECIES ON NEMATODE PREDATION.

Organic Source	Avg. nos. of *Panagrellus redivivus* recovered
Sugar cane filter press mud	3,590
Ground oat hulls	1,225
Unground oat hulls	350
Corn bran	38,280
Fungus Species	Avg. nos. of *Panagrellus redivivus* recovered
Dactylella sp.	12,675
Dactylaria thaumasia	16,588
Arthrobotrys musiformis	1,506
Arthrobotrys oligospora	9,900
Dactylella ellipsospora	13,413

TABLE 3.—GROWTH OF *Arthrobotrys musiformis* ON GROVE COVER CROP SUBSTRATES.

Substrate	Growth
Black nightshade	None
Bermuda grass	None
Crabgrass	None
Cutleaf evening Primrose	Very sparse
Lambsquarter pigweed	Light to moderate
Jerusalem oak	Fair
Maidencane	Moderate to good
Mexican clover	None
Natal grass	*Excellent
Pangola grass	None
Ragweed	None
Red-rooted pigweed	Sparse
Sandspur	Good
Shepard's purse	None
Spanish needle	None
Vasey grass	*Very good

roseum (Nees) Stapf. & Hubb.) proved to be highly suitable substrates for fungal growth. If organic matter were shown to be a necessary supplement for growth of *A. musiformis*, then cultivation of these two grasses could be encouraged. Of similar importance was the ability of the fungus to grow on dead citrus roots. Since live roots are invariably formed in an area where dead and decaying roots exist, the persistence of the fungus in that area is enhanced by its ability to grow on the dead citrus material and insure its availability for trapping nematodes seeking entrance into the live roots.

FORTUITOUS OCCURRENCE OF ARTHROBOTRYS MUSIFORMIS IN CITRUS GROVE SOILS

Arthrobotrys musiformis (a conidial Hyphomycete that forms reticulate trapping devices) was shown to be a suitable predator of the burrowing nematode. Its utility for continued testing was enhanced by its relatively rapid growth in culture, its formation of abundant conidia, and its ability to form chlamydospores (thick-walled "resting" structures capable of germination upon the advent of proper growth conditions). Since experiments were contemplated involving incorporation of the fungus in grove soils, the question naturally arose concerning its frequency of occurrence in a representative orange grove.

A 31-year-old grove containing Pineapple orange trees on rough lemon rootstock was selected, and soil samples obtained from a 1- to 2-ft. depth on opposing sides of 16 trees selected at random. Pinches of soil from each sample were implanted on agar and the nematophagous fungi present cultured as described previously.

Arthrobotrys musiformis was isolated from only four of the 32 samples showing that it was present, although not abundantly, in that particular grove. Accordingly, it seemed that if nematode control with *A. musiformis* were to be investigated, the fungus should be added to soil and assumption not made that it already extensively occurred naturally.

EFFECT OF TWO NEMATODE-TRAPPING FUNGI GROWING ON TWO ORGANIC SUBSTRATES ON BURROWING NEMATODE-INFECTED GRAPEFRUIT SEEDLINGS

Quart jars containing sugar cane filter press mud or oat hulls were inoculated with *A. musiformis* or *Dactylaria thaumasia*. After five weeks, the fungi had grown throughout the substrates. Each type of fungus-impregnated organic matter, alone and in a 1:1 combination, was applied at a rate of 10 or 30 T per acre to five replicate two-year-old nematode-infected Duncan grapefruit seedlings in 46 oz cans. Fifteen plants were maintained as controls.

After 13 weeks, nematode extractions were made from the soil within each can as well as from the roots of each seedling. All types of organic matter used, regardless of rate of application, increased severity of root infection as compared to untreated controls, which conforms to the results of Nolte (35). Although only *D. thaumasia* slightly decreased numbers of *R. similis* in the soil, nematodes occurred in higher numbers in roots of plants treated with fungi than in roots of control plants. Thus it seems that, in this test, applications of organic matter stimulated the formation of larger root systems that supported increased nematode populations on which the trapping fungi had no effect.

RESPONSE OF NEMATODE-INFECTED SEEDLINGS TO SOIL APPLICATION OF ARTHROBOTRYS MUSIFORMIS AND OAT HULLS

Using the same procedure as in the preceding experiment, oat hulls supporting a luxuriant growth of the fungus were applied at rates of 25 and 50 T per acre to infected grapefruit seedlings in 46 oz cans. The oat hull-fungus material was either mixed with the upper third or with all the soil in the cans. Moistened oat hulls without fungus were mixed at the rate of 50 T per acre with the soil in which control plants were growing. There were six replicate plants per treatment. After seven months, burrowing nematodes were isolated by incubation of roots in plastic bags for one week.

It was found that plants treated with oathull-fungus mixture had greater root nematode populations than controls receiving only oat hulls. As in the previous test, organic matter did not enhance activity of the trapping fungus since highest populations of *R. similis* occurred in plants receiving oat hulls at the 50 T per acre rate.

MASS CULTURE OF ARTHROBOTRYS MUSIFORMIS

Since incorporation of the fungus into the soil would necessitate the use of large quantities of the organism, a method described by Lumb & Duddington (29) for producing in bulk a number of predaceous Hyphomycetes belonging to the Moniliaceae was investigated for the growth of *A. musiformis*. According to their specifications, a pH adjusted, chemically defined medium was prepared in which attempts were made to grow *A. musiformis* in shake culture. Results were discouraging.

Through the efforts of personnel at the Eli Lilly Company of Indianapolis, Indiana, who were valued cooperators in this phase of the research, *A. musiformis* was grown in sizeable amounts for two days at 25 C in deep

tank fermentation. Although the culture period was of such short duration that it did not permit conidial formation, the mycelium, when harvested, partially dried, mixed and ground with microcel (an inert mineral carrier marketed by the Johns Mansville Corp.) was wholly viable and well adapted to use in the contemplated experiments.

Storage tests were conducted whereby small amounts of this fungus preparation (containing 60% fungus material) were subjected to greenhouse, laboratory, and refrigerator temperatures for a year. The material became non-viable within a month when stored at 72-94 F in the greenhouse, and non-viable within two months' storage in the laboratory at 78 F. When stored in the refrigerator at 35 F, the preparation remained viable for more than a year.

PERSISTENCE OF ARTHROBOTRYS MUSIFORMIS IN SOIL

It was shown that *A. musiformis*, as mycelial fragments mixed with microcel carrier (hereafter referred to as "fungus-microcel") did not retain its viability for periods longer than two months except when stored at 35 F. The possibility that incorporation of the preparation with soil would offer different results was investigated.

Ten g of viable fungus-microcel were thoroughly mixed with each of four pints of steamed field soil and four pints of non-steamed, freshly dug subsoil, enclosed in plastic bags, and stored at 40, 54, 65, and 70 F. Samples of soil from each bag were placed on corn meal agar each month for two months and the cultures incubated.

After a month, *A. musiformis* was not isolated from any of the field soil samples with which it was originally mixed, although *A. oligospora*, as a fortuitous infestation, was detected in the field soil stored at 40 and 54 F. Only the samples of steamed soil stored at 40 and 54 F contained *A. musiformis* after a month.

Neither of the two soil samples stored at the four temperatures contained the fungus after two months' storage.

PROTECTIVE AND CURATIVE TREATMENTS OF CITRUS SEEDLINGS WITH FUNGUS-MICROCEL AND PEANUT HULLS

The fungus-microcel preparation had been found to lose viability quickly when either stored at room temperatures or mixed with soil. It was desirable to test the influence of organic matter on the potential effectiveness of the preparation as a protectant for healthy seedlings against burrowing nematodes and also as a curative treatment for seedlings already infected.

Three replicate healthy nine-month-old and nematode-infected 12-month-old Duncan grapefruit seedlings in 46 oz cans were treated with fungus-microcel at rates of 0 lb., 350 lb., ½ T, 1 T, or 5 T per acre, with and without crushed peanut hulls at the rate of 2 T per acre. Application of these materials to healthy plants was to determine whether the roots would be adequately protected against subsequent nematode penetration. Therefore, 8 g of chopped *R. similis*-infected citrus roots were added to the soil in cans containing healthy seedlings four days after materials were incorporated into the soil.

This test was terminated after seven months and data as shown in Table 4 were obtained. Average weight of parts from fungus-treated plants

TABLE 4.—PROTECTIVE AND CURATIVE TREATMENT OF GRAPEFRUIT SEEDLINGS WITH FUNGUS-MICROCEL MIXTURE AND PEANUT HULLS.

Type	Treatment: Fungus-microcel 350 #/A	½ T/A	1 T/A	5 T/A	Peanut hulls	Avg. aerial prt. wt. in g	Avg. Estimated R. similis per g feeder root	No. recoveries of A. musiformis from 3 repl. plants
Pre-infection (Protectant)	X					19.4	2.1	3
		X				18.9	30.7	3
			X			16.0	11.3	3
				X		20.0	8.1	2
		Control				17.4	8.7	0
	X				X	15.5	5.2	3
		X			X	16.6	11.8	3
			X		X	16.7	6.2	3
		Control			X	16.4	4.8	2
Post-infection (Curative)	X					4.4	8.6	3
		X				11.0	1.4	3
			X			7.3	7.4	1
				X		6.6	0.3	2
		Control				2.2	3.7	1
	X				X	3.4	1.2	3
		X			X	5.0	1.8	3
			X		X	11.2	1.2	3
		Control			X	3.9	0.7	1

were generally greater than that of corresponding controls or plants not treated with fungus material. There was no consistent reduction of nematodes from feeder roots due to treatment with the fungus-microcel. No one rate of fungus treatment was better than others despite the presence of peanut hulls.

From the soil around 42 plants that originally received the fungus preparation, 38, or 90%, yielded *A. musiformis,* whereas only 4 out of 12, or 33%, of the control plants yielded the fungus in culture. This test was conducted in the greenhouse from May to January when soil temperatures within cans fluctuated from 42 F to 92 F.

TREATMENT OF MATURE TREES WITH FUNGUS-MICROCEL MIXTURE

Six nematode-infected 31-year-old Pineapple orange trees on rough lemon rootstock were treated at rates of 50, 100, or 200 lbs per acre with *A. musiformis*-microcel preparation (fungus microcel). Six trees received no amendments and were designated as controls. The fungus material was evenly distributed and then disced in to a depth of 5 to 6 in. The experimental area was then irrigated.

Root and soil samples were taken from each tree once a month. Soil was placed on corn meal agar to test for the presence of the fungus; roots were incubated for a week in plastic bags and the total evacuating *Radopholus similis* population counted.

Results of this test appear in Table 5. There was no evidence of nema-

TABLE 5.—TREATMENT OF MATURE, NEMATIZED CITRUS TREES WITH FUNGUS-MICROCEL MIXTURE.

Fungus appl. in lbs/A	Before Trmt.	Avg. No. *Radopholus similis* per g of feeder root 1st mo.	2nd mo.	3rd mo.	4th mo.	6th mo.	7th mo.	8th mo.	Avg.
None	0.7	6.9	8.7	2.8	3.1	0.8	4.0	1.8	3.6
50	0.6	2.4	2.0	4.1	2.1	1.6	1.1	0.9	1.9
100	17.4	18.1	27.4	6.9	4.5	0.6	2.5	2.3	9.9
200	4.1	8.6	5.1	7.9	3.1	4.7	0.4	3.9	4.7
% recovery of *A. musiformis* from treated trees		17	17	44	22	44	33	28	29
% recovery of *A. musiformis* from untreated trees		0	0	50	17	83	66	33	31

tode control by the fungus. Average numbers of *R. similis* per gram of feeder root varied considerably but generally were too low to reflect drastic population changes. *Arthrobotrys musiformis* was recovered from only 29% of the trees receiving the fungus preparation while, enigmatically, it was detected in 31% of the control trees. Recovery of the fungus from both treated and nontreated soils was greater during the winter months.

ADDITIONAL TRIALS WITH DACTYLELLA DRECHSLERI AND ORGANIC MATTER

The greenhouse tests hitherto described usually utilized *A. musiformis*, which forms sticky meshes for capturing nematodes. A newly described fungus from Florida, *Dactylella drechsleri* Tarjan (45), which forms sticky knob-like trapping organs was cultured on corn meal agar. A sufficient quantity of the fungus-impregnated agar was macerated with water in a Waring blender and then added to the soil of seven grapefruit seedlings in which sugar cane filter press mud at the rate of 25 T per acre had been incorporated. Seven control plants with this organic matter amendment received plain agar and water. After 30 weeks, nematodes were extracted from the roots as in previous tests. There seemed to be some control of *R. similis* since treatments contained only two-thirds of the number of nematodes in roots of controls. However, these nematode counts were generally too low for much dependency to be placed on the success of treatment.

USE OF LIME PEANUT HULLS, MANURE AND FUNGUS FOR TREATMENT OF INFECTED GRAPEFRUIT SEEDLINGS

The tests previously described have pointed to the inadequacy of treatment of nematized plants with fungus and organic matter for obtaining nematode control. Although lime has been reported as stimulating an increase in nematode population (1), its use has been recommended by some growers as necessary for maintaining proper growth conditions for nematode-infected trees. Accordingly, an experiment was designed to

investigate the value of lime alone and in combination with *A. musiformis* and organic matter for enhancing the predacity of the fungus to nematodes.

Arthrobotrys musiformis was cultured on crushed peanut hulls and applied at a rate of 2 T per acre in various combinations with a fine mesh, high calcium lime at 2, 5, 15 and 30 T per acre, and a commercial cattle and sheep manure at 2 T per acre to five grapefruit seedlings 15-months-

TABLE 6.— EFFECT OF LIME, MANURE, PEANUT HULLS, AND *Arthrobotrys musiformis* ON NEMATODE-INFECTED GRAPEFRUIT SEEDLINGS.

1	2	3	4	5	6	7	8	9	10
Treatment Code[1]	Plant Condition Code[2]	Aerial Part, Maximum Length in cm	Aerial Part, Weight in g	Root System Weight in g	pH of Soil ± SE After 1 Month	pH of Soil ± SE at End of Expt.	No. *R. similis* per Pint of Soil	No. *R. similis* per g of Feeder Root	No. Recoveries of *A. musiformis* from 5 Repl. Plants
L-2	13	22.2	13.8	10.4	7.1 ± .20	6.5 ± .08	7.6	1.42	5
L-5	10	25.8	10.5	8.1	7.5 ± .15	6.7 ± .07	13.0	1.56	5
L-15	8	26.6	13.1	8.8	9.0 ± .08	7.3 ± .09	9.8	2.11	3
L-30	6	24.5	9.5	7.4	9.6 ± .12	7.6 ± .05	4.2	0.65	4
LM-2	13	30.9	14.5	9.9	7.3 ± .10	6.7 ± .17	17.6	3.52	5
LM-5	8	26.0	13.0	6.6	7.5 ± .18	6.4 ± .10	28.6	1.73	4
LM-15	7	26.4	9.4	7.3	9.3 ± .09	6.9 ± .05	5.8	1.15	2
LM-30	6	23.7	10.4	8.0	10.2 ± .08	6.9 ± .04	4.2	0.48	3
LF-2	12	31.8	11.8	9.0	7.2 ± .13	6.5 ± .11	6.0	0.93	5
LF-5	9	31.1	14.9	11.2	7.5 ∓ .08	6.8 ∓ .08	25.2	1.66	4
LF-15	6	23.2	9.3	7.2	9.2 ± .08	7.1 ± .08	17.2	1.39	4
LF-30	7	24.8	11.9	9.3	10.1 ± .05	7.4 ± .05	26.4	2.06	3
LFM-2	8	22.0	9.5	7.3	7.5 ± .10	6.6 ± .08	14.4	1.29	5
LFM-5	9	27.0	10.2	7.3	7.3 ± .08	6.9 ± .12	12.6	0.66	4
LFM-15	6	20.2	7.2	5.7	8.8 ± .03	7.1 ± .04	39.8	1.61	5
LEM-30	7	21.5	8.7	7.4	9.9 ∓ .07	7.3 ∓ .11	6.0	0.41	4
C	12	24.5	8.9	6.6	5.7 ± .08	5.3 ± .20	2.4	1.18	3
CM	13	43.3	19.2	10.9	5.8 ± .14	5.9 ± .09	9.4	1.87	0
CF	14	43.7	21.8	13.6	5.7 ± .07	5.9 ± .12	11.4	1.76	3
CFM	13	42.9	24.2	14.6	5.8 ± .11	6.0 ± .10	5.2	0.26	5

[1]Treatment code:
L=Lime
F=*A. musiformis*
M=Manure
C=Control plants
Nos. represent rate of application of lime in T per acre.

[2]The plant condition code is a cumulative numeral score; the higher the code value, the better the all-round plant appearance. It is composed of the following sub-ratings:

Iron Chlorosis:
None=4
Slight=3
Light=2
Moderate=1
Severe=0

New Growth Formation:
None=0
Slight=1
Light=2
Moderate=3
Abundant=4

Plant Defoliation:
None=4
Slight=3
Light=2
Moderate=1
Severe=0

General Leaf Width:
Narrow=1
Average=2
Wide=3

old and infected with burrowing nematodes. Various combinations of these materials were thoroughly mixed with the soil and the plants placed in 6-in. pots.

Averages for data obtained after 10 months are shown in Table 6. In treating infected plants with lime only (L), increasing the concentration of lime generally resulted in decreased weight of plant parts (cols. 2-5) and caused foliar yellowing. Although the 30 T per acre rate of lime gave lower nematode counts (cols. 8-9), counts were relatively high when only ½ the rate was used. Adding either manure or fungus or both to limed soil did not appreciably change the pattern of decreased weight of the plant parts from that of the treatment with lime alone. These control plants receiving amendments other than lime gave both the highest plant condition code readings (col. 2) and heavier plant parts (cols. 4-5) at the end of the test. Whereas average numbers of *Radopholus similis* in the soil of controls were lower than in lime treatments (col. 8), only the CFM treatment had a lower count of *R. similis* per g of root when compared with the lime treatments. *Arthrobotrys musiformis* was present in the soil of almost all treatments, including controls (col. 10). Apparently the fungus was either already established in the potting soil used or it spread from treated pots to the untreated. The latter possibility appears most likely since the fungus can fruit on the surface of treated soil and air currents could conceivably disseminate the conidia.

EFFECT OF LIME AND ORGANIC MATTER ON PREDATION BY DACTYLELLA DRECHSLERI

Combinations of lime and organic matter with *A. musiformis*, a reticulate mycelial trapping fungus, did not result in appreciable reductions of nematodes in previous tests. Therefore, a similar trial was conducted with *D. drechsleri*, a sticky-knobbed trapping fungus, which was cultured on moistened peanut hulls and then added to soil of 18 replicate 16-month-old grapefruit seedlings at a rate of 7 T per acre. Nine of these were also treated with high calcium lime at 5 T per acre while a third control group received only peanut hulls at 7 T per acre.

Data shown in Table 7 were obtained after five months, reflecting the average values for nine replicate plants. Those plants which had been treated with lime had less aerial and root tissue than those in the other two treatments, while having a significantly greater number of nematodes

TABLE 7.—EFFECT OF LIME, PEANUT HULLS, AND *Dactylella drechsleri* ON INFECTED GRAPEFRUIT SEEDLINGS.

Treatment	Aerial Parts		Roots		Soil	
	Height in cm	Wt. in g	Wt. in g	Estimated *R. similis* per g root	pH	No. of plants with trapping fungi
Peanut hulls (Controls)	20.8	6.1	5.9	9.2	6.4	3
Fungus-impregnated peanut hulls	19.1	6.6	6.2	8.1	6.6	8
Fungus-impregnated peanut hulls and lime	15.8	4.1	4.5	17.2	7.7	7

in the roots. *Dactylella drechsleri* failed to become established in the soil and was not subsequently recovered, although *Arthrobotrys musiformis* and/or *A. oligospora* were present in the soil as indicated in Table 7.

FIELD TREATMENT OF MATURE TREES WITH DOLOMITE, FUNGUS-MICROCEL, AND ORGANIC MATTER

In an earlier test, mature orange trees had been treated with as much as 200 lbs per acre of the fungus-microcel mixture with no evidence of nematode control having been detected. Another test was conducted using this fungus preparation at the rate of 2 lbs per tree, dolomite at 2 T per acre, and a 1:1 mixture of peanut hulls and sugar cane bagasse at 2 T per acre applied to two replicate 31-year-old Pineapple orange trees on rough lemon rootstock in all possible combinations. The material was applied to disked soil and raked in to a depth of 6 in., following which the trees were irrigated. Soil and root samples from each tree were obtained at three-month intervals for a year.

There was no consistent evidence of nematode control due to application of fungus mixture, nor could correlation be made between nematode counts and the presence of lime or organic matter. Application of dolomite did not appreciably change the soil pH. Although *Arthrobotrys musiformis* was recovered from 53% of the areas to which it was originally applied, it was also recovered from 41% of the control areas to which it had not been applied. *Arthrobotrys oligospora* appeared in cultures almost as frequently as *A. musiformis.*

PRE- AND POST-INFECTION TREATMENT OF FIELD-TRANSPLANTED GRAPEFRUIT SEEDLINGS WITH LIME, FUNGUS AND ORGANIC MATTER

Nematode infections of seedlings are easier to control than infections of large trees by virtue of the limited root system area to be treated. Although this principle prompted numerous greenhouse tests, extreme fluctuations in temperature were suspected of influencing the results obtained. Hence, a final field experiment was conducted with 17-month-old grapefruit seedlings planted 1½ feet apart between two rows of mature nematode-infected orange trees. Fungus-microcel was applied at a rate of 500 lbs per acre, high calcium fine mesh lime at 10 T per acre, and peanut hulls at 10 T per acre in the combinations shown for Treatments A-G in Table 8. Treatment H with the fungus material was at 50 lbs per acre while Treatment I was at 5,000 lbs per acre. Plants used for Treatments A-J were already infected with burrowing nematodes. Treatment K consisted of application of the fungus mixture at 500 lbs per acre to healthy plants while Treatment L served as the control to Treatment K. Treatment K was designed to show whether the prior placement of the fungus in the soil would prevent or lessen subsequent penetration of the roots by nematodes. Accordingly, 10 g of chopped nematode-infected citrus roots were added to Treatments K and L one week after incorporation of the fungus in the soil. Proper moisture conditions were maintained with overhead irrigation during the five months this test was conducted.

Although nematode counts for Treatments A, D, and G were low as compared to those of controls (J), the disparity in nema count between these three treatments and related Treatments B, C, E, and F, which had

TABLE 8.—PRE- AND POST-INFECTION TREATMENT OF FIELD-TRANSPLANTED GRAPEFRUIT SEEDLINGS WITH FUNGUS, LIME AND ORGANIC MATTER.

Treatment[1]						Nematode-trapping fungi isolated from 8 replicate plants		
Type	Fungus 500 lbs/A.	Lime 10 T/A.	Hulls 10 T/A.	Avg. no. *R. similis* per g root	Avg. pH of soil	*A. musiformis*	*A. oligospora*	others
A	—	+	+	3.0	7.1	4	5	4
B	—	—	+	19.8	6.3	4	3	3
C	—	+	—	20.8	6.9	0	2	3
D	+	+	+	6.9	6.9	2	0	2
E	+	+	—	29.6	7.1	2	0	2
F	+	—	+	21.5	5.9	4	3	4
G	+	—	—	8.6	5.2	4	5	2
H - Fungus-microcel at 50 lbs/Acre				17.6	4.9	3	2	1
I - Fungus-microcel at 5000 lbs/Acre				14.6	5.1	5	4	1
J - Untreated controls				17.0	5.1	3	3	2
K - Pre-infection application of fungus-microcel at 500 lbs/Acre				13.0	5.3	4	2	0
L - Untreated controls				10.0	5.5	3	2	4

[1]Treatments A-J applied to *R. similis*-infected plants; treatments K-L to healthy plants to the soil of which, after one week, was added 10 g of nematode-infected roots.

mean counts higher than the control, strongly suggest that the results were due to chance. Results from earlier tests tend to confirm this supposition. As in previous tests, neither of the amendments, either single or in combination, effectively or consistently reduced or eliminated the nematodes. Adding the fungus material to the soil prior to the introduction of nematodes (Treatment K) did not prevent or even reduce the severity of infection. Recovery of *A. musiformis* from the soil was erratic. It was found in the soil of only 45% of the plants originally treated while it was present in the soil of 37% of the plants that were not treated with it.

FUNGAL COMPOSITION OF CITRUS GROVE SOIL PREVIOUSLY TREATED WITH FUNGUS-MICROCEL

The tests previously described have almost invariably failed to reduce numbers of burrowing nematodes associated with citrus roots. One likely reason for this may have been failure of the fungus additive to become established in the soil as claimed by Mankau (32). Then too, the possibility exists that the fungus might not penetrate deeper than the upper few inches of the soil in which it was originally introduced.

An area was arbitrarily selected within a citrus grove to which fungus-microcel had been applied at 200 lbs per acre and disked in to a depth of 5 to 6 in. three months before. A vertical wall of soil and tree roots was exposed, underlying the drip margin of a tree, to a depth of 44 in. at which point the clay layer in the soil was present. The soil profile consisted of an upper dark organic layer 2½ in. in depth, followed by a white sandy layer from 2½ to 4 in. deep, and a generally homogeneous yellow subsoil layer down to the clay layer. Inch cubes of soil and roots were collected at 1-in. intervals from 0 to 12 in., 2-in. intervals from 12 to 24 in., at 3-in. intervals from 24 to 36 in., and at 4-in. intervals down to 44 in. In the

laboratory small amounts of the soil were implanted on corn meal agar. Feeder roots in the samples were surface decontaminated with 2.8% sodium hypochlorite, washed with distilled water, dried with sterile filter paper, and placed on agar. After 11 days, the fungi listed in Table 9 were found growing from the roots and soil.

Nematophagous fungi were present down to a depth of 8 in. *Arthrobotrys musiformis* was recovered at depths to 4 in., but only A. oligospora occurred at the 8-in. depth.

ANTAGONISMS BETWEEN ARTHROBOTRYS MUSIFORMIS AND OTHER SOIL FUNGI

It appeared likely that the difficulty in getting *A. musiformis* to persist in soil might be due to the presence of antagonistic fungi. In order to test this possibility, inoculations with pure cultures of the fungi listed in Table

TABLE 9.—FUNGUS COMPOSITION OF A CITRUS GROVE SOIL PREVIOUSLY TREATED WITH FUNGUS-MICROCEL MIX.

Soil depth in in.	Fungi Associated with the Soil
0	Arthrobotrys oligospora, A. musiformis, Dactyella, Gliocladiopsis
1	A. oligiospora, A. musiformis
2	A. oligospora, A. musiformis, Fusarium
3	A. oligospora, A. musiformis, Gliocladium, Gliocladiopsis, unidentified spp.
4	A. oligospora, Trichoderma
5	Trichoderma, Penicillium
6	Trichoderma, Penicillium, Cladosporium?
7	Trichoderma, Penicillium
8	A. oligospora, Tichoderma, Penicillium, unidentified spp.
9	Helminthosporium, Fusarium, Trichoderma, Penicillium
10	Cladosporium?, Fusarium, Trichoderma, Penicillium
11	Trichoderma, Fusarium, Penicillium
12	Trichoderma
14	Trichoderma, Fusarium, Penicillium
16	Trichoderma, Fusarium, Penicillium
18	Trichoderma, Fusarium, Penicillium
20	Trichoderma, Fusarium, Penicillium
22	Trichoderma, Fusarium, Penicillium
24	Trichoderma, Penicillium, Gliocladium
27	Trichoderma, Penicillium
30	Trichoderma, Penicillium, Hormodendron
33	Trichoderma, Penicillium, Hormodendron
36	Trichoderma, Penicillium
40	Trichoderma, Penicillium spp., Fusarium
44	Trichoderma, Penicillium, Stachobotrys

Root depth in in.	Fungi Associated with the Roots
3	Fusarium
3	Fusarium, Torula?
6	Fusarium, Torula?, Periconia
7	Fusarium
8	Penicillium sp.
9	Fusarium, Penicillium
10	Fusarium, Penicillium
12-30	Mostly Penicillium, Fusarium; roots from 24 in. yielded Gliocladium

TABLE 10.—COMPATIBILITY OF *Arthrobotrys musiformis* WITH ASSOCIATED FUNGI.

Origin	Fungus	Antagonism	Intergrowth
Root	Fusarium sp. 1		+
	Fusarium sp. 2		+
	Gliocladium	+[2]	
	Periconia		+
	Penicillium		+
	Torula?		+
	Unidentified sp. 1		+
	Unidentified sp. 2		+
Soil	Arthrobotrys oligospora		+
	Cladosporium?		+
	Fusarium sp. 1		+
	Fusarium sp. 2		+
	Gliocladiopsis		+
	Gliocladium	+	
	Helminthosporium	+[1]	
	Hormodendron		+
	Penicillium		+
	Stachobotrys		+
	Trichoderma	+[2]	
	Unidentified sp. 1		+
	Unidentified sp. 2		+
	Unidentified sp. 3		+

[1]Antagonism appeared physical, not chemical; intergrowth very sparse.
[2]Strong antagonism of a chemical nature.

9 were made to one side of a Petri dish containing corn meal agar. After three days the opposite side was inoculated with *A. musiformis*. Plates were incubated at 75 F for two weeks and then examined for antibiosis.

As shown in Table 10, only *Gliocladium* and *Trichoderma* proved to be chemically antagonistic to *A. musiformis*. When these two fungi were introduced into an agar culture already overgrown with *A. musiformis*, both fungi became established but failed to grow laterally, indicating that they would not displace *A. musiformis* already established on agar. *Gliocladium* and *Trichoderma* have already been reported as producing toxins by Weindling (49), but were not isolated by Mankau (32), who reported similar antagonisms from *Penicillium* spp. and *Aspergillus terreus*.

Trichoderma, a common soil inhabitant, was found occurring at depths from 4 to 44 in. while *Gliocladium* was found at depths of 3 in. and 24 in. The occurrence of these fungi could account for failures to establish nematophagous fungi in the field.

DISCUSSION

Published accounts of experiments with predaceous fungi show that biological control of soil-inhabiting nematodes is possible, albeit erratic. The work reported in this paper showed that application of fungi to soil in which nematode-diseased citrus plants were growing did not control parasites. There are no reports of successful therapy of plant nematodes with trapping fungi, hence it may be that the present experiments were

destined for failure in that they attempted a means of control that may not be possible. Similar discouraging results were encountered when these fungi were applied to soil prior to infestation with nematodes. The light, friable nature of the soil in these tests may also have contributed materially to the poor results obtained. Such soils are more readily affected by higher air temperatures, and it has previously been shown that *Arthrobotrys musiformis* would not remain viable for two months at temperatures of 40 F. and 54 F. when applied as a microcel preparation to autoclaved soil. Then, too, light soils more rapidly lose the moisture which is so critically needed for proper growth of the introduced fungi, as shown by the work of Hams & Wilkin (20). These investigators also found that peak growth (and presumed maximum predation) of *Cylindrocarpon radicicola,* as determined by respirometric determination, occurred about 12-15 days after implantation of this trapping fungus in the soil. In none of the tests herein reported were nematode counts obtained so soon after treatment, thus suggesting that peak activity of *A. musiformis* may have occurred and that nematode populations had since increased.

Because of the failures experienced in effecting nematode control and also in implementing artificial infestations in field soils, only one attempt was made to determine the depth at which these nematophagous fungi existed. The fungus originally applied, *A. musiformis,* was found only to a depth of 4 in. while *A. oligospora,* a closely related predaceous form, was found to a depth of 8 in. Yet, survival of these fungi in soil is so strongly influenced by other factors that the erroneous conclusion should not be made that they cannot occur deeper. On several occasions I have isolated nematode-trapping fungi from soil samples obtained at depths of 1 to 2 ft.

The hope that incorporation of organic matter in soil would promote activity of trapping fungi was not realized. Although such application of organic material did benefit the plants nutritionally, the net result seemed to be a stimulation of root growth which supported more nematodes but failed to increase nematophagous fungus activity. Although rates as high as 50 T per acre of organic matter were applied, there was no indication that these were adequate to stimulate fungus predation.

Of paramount importance was the discovery of soil fungi antagonistic to *A. musiformis* growing at almost all depths sampled. Of these, *Trichoderma* (which is equally antagonistic to many other fungi) occurs so frequently and even prolifically that one wonders how any introduced fungus could compete or even survive. Without doubt, under natural conditions antagonistic fungi, bacteria, etc. act as inhibitors to the widespread growth of nematophagous fungi which, despite these inimical influences, do accomplish much more control of noxious nematodes than is generally recognized.

Arthrobotrys musiformis was the trapping fungus selected for most of these studies because it is fast-growing in culture, forms conidia readily, can be found in a variety of natural habitats, can grow as a saprophyte in organic matter when no nematodes are present, and is capable of surviving under adverse conditions by means of thick-walled chlamydospores. Despite these many advantages, it is possible that this species may not be as predaceous to burrowing nematodes as other fungus species, and, *ipso facto,* was the wrong choice of trapping organism. With this realization, additional tests with *A. oligospora* (a closely related species of similar habit to *A. musiformis*) are now being conducted. Then, too, the fungus-microcel

mixture mainly used for these tests consisted of viable mycelial fragments of *A. musiformis* which would grow vegetatively in the soil if suitable conditions existed but might be structurally deficient for remaining alive upon the sudden advent of unfavorable growing conditions. Consequently, the production of chlamydospores of *A. musiformis* and their application to and activity in the soil is predominating my current research on the problem.

SUMMARY

Results from six greenhouse and three field tests using nematophagous fungi, organic material, and lime applied at different rates as pre- or post-infection treatments failed to reduce numbers of *Radopholus similis* in roots of citrus seedlings or mature trees growing in sandy loam. Whereas various types of organic matter would support growth of these fungi, incorporation of such materials to the soil did not promote nematode predation. Heavy applications of high calcium lime did tend to reduce the number of nematodes recovered from roots of treated plants, but at the expense of plant growth which was affected adversely by excess lime. Considerable difficulty was encountered in establishing fungi added to the soil. It was found that *Trichoderma* sp. and *Gliocladium* sp. (normal soil inhabitants) were antagonistic to *A. musiformis*, the principal fungus used in these studies.

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Reaction of Guatemalan Light-Insensitive Kenaf Selections to Root-Knot Nematodes[1]

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The development of light-insensitive varieties of kenaf, *Hibiscus cannabinus* L. in Guatemala for use in Latin America, and kenaf lines which exhibit a degree of tolerance to the root-knot nematode *Meloidogyne incognita acrita* Chitwood 1949, in Florida were reported in 1961 (1,2). These developments focus attention on the possibility of lengthening the fiber harvest period into the short day fall months, as well as indicating the potential of lessening the hazard of reduced yields and premature dehydration of plants from nematode damage (3).

Illustrated in Figure 1 is the growth of light-insensitive and light-sensitive varieties of kenaf planted in September in Palm Beach County, Florida. Of particular significance would be the development of a single variety of kenaf possessing both these desirable characteristics, i.e., light-insensitiveness and tolerance to root-knot nematodes. This report is concerned with an initial step in an attempt being made to develop such a photo-period insensitive, nematode tolerant variety of kenaf.

Thirty-nine lines of kenaf developed for photo-period insensitivity were evaluated for their reaction to a heavy population of the root-knot nematode *M. incognita acrita* in the U.S. Department of Agriculture nematode nursery near Lake Worth, Florida.

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[1]Cooperative investigations of the Crops Research Division, Agricultural Engineering Research Division, ARS, U.S.D.A., and the Everglades Experiment Station, University of Florida Agricultural Experiment Stations, Belle Glade, Florida.

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Fig. 1.—Left: A light-insensitive kenaf variety, G-51. Right: Cuba-2032, also a light insensitive variety on left with Cubano, a light sensitive variety on right. All plantings in September.

Criteria for evaluating reaction in descending order of attributed importance were: (a) ability to produce seed under heavy nematode attack, (b) ability to produce flowers under nematode attack, (c) ability of plants to make good vegetative growth under test conditions, and (d) severity of root galls caused by *M. incognita acrita*.

Seed were planted April 11, 1961. Galls had formed to some degree on roots of all plants by July 10. Results will be reported elsewhere after the

Table 1.—Guatemalan Kenaf Lines Tested for Reaction to *Meloidogyne incognita acrita* According to Flowering and Seed Producing Ability Grown in Heavily Infested Soil.

Line	Flowered	Set seed	Line	Flowered	Set seed
1. G 49	+	+	20. G 36-4	—	—
2. G 63-C	+	+	21. G 17-B	—	—
3. G 65-2	+	+	22. G 36-11	—	—
4. G 44	+	+	23. G 47	—	—
5. G 38B1	+	+	24. G 30-31	—	—
6. G 50B	+	+	25. G 45	—	—
7. G 48	+	+	26. G 63A	—	—
8. G 57B1	+	+	27. G 35A	—	—
9. G 57C1	+	+	28. G 47B	—	—
10. G 4	+	+	29. G 50A	—	—
11. G 36-5	+	—	30. G 14A	—	—
12. G 38-8	+	—	31. G 2B	—	—
13. G 21A	+	—	32. G 27	—	—
14. G 50C	+	—	33. G 7	—	—
15. G 46	+	—	34. G 66B	—	—
16. G 47A	+	—	35. G 6A	—	—
17. G 21	+	—	36. G 14	—	—
18. G 66A	+	—	37. G 50C	—	—
19. G 36-1	+	—	38. G 29	—	—
			39. G 52-1	—	—

lines have been tested to the several individual species of root-knot nematode which are present in Florida.

Plants within 10 lines had flowered and produced seed by August 1. Table 1 presents seed and flowering results. Plants in three lines, G 49, G 65-2, and G 63-C produced seed in all replications of the test, and more than half the plants producing seed in the entire test were within these lines. Plants in nine other lines flowered but failed to produce seed. Twenty lines failed to flower and were killed before or shortly after August 1.

Inasmuch as the three lines G 49, G 65-2, and G 63-c all produced seed in all replications of the test and also contained more than half the plants producing seed there is an indication that a discernible degree of tolerance to the nematode M. *incognita acrita* exists within these lines.

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Drainage Characteristics of Leon and Felda Sands: I. Water Table Behavior[1]

R. B. DIAMOND, L. C. HAMMOND, AND J. M. MYERS[2]

The solution of drainage problems is of major importance in Florida where expanding agriculaure is moving to the poorly drained soils of the flatwoods and marshes (4). Much of this land, some 16 million acres, is satisfactory for cropland when drained. Open-ditch systems are generally used, but clay tile has been used for more than 40 years in limited areas under intense vegetable production (4,5,6). However, in order to design economical drainage systems much more information than now available is needed. This includes the interrelationships of crop growth, rainfall, position and behavior of water table, soil physical properties, and drain depth and spacings. Excellent reviews of recent drainage literature have been published (3,8). This paper presents data on the position and behavior of the water table in relation to certain soil physical properties, rainfall situations, and ditch spacings on Leon and Felda sands.

MATERIALS AND METHODS

Experimental drainage plots consisting of open ditches about 5 feet in depth were established on Leon sand at Gainesville and in Felda sand near

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Ft. Pierce. The Gainesville installation consisted of single plots 67, 133, and 200 feet square planted to Pensacola bahiagrass. The ditches were placed on 2 sides of the 200- and 133-foot plots and on 3 sides of the 67-foot plot. Single fallow plots 135 and 405 feet wide and approximately 1600 feet long were used near Ft. Pierce in the Cloud Grove of the Minute Maid Company.

The Leon profile consisted of sands ranging in thickness from 13 to 24 inches over an organic pan about 6 inches thick beneath which sands extended downward to finer textured materials at 60 to 84 inches. The Felda profile was composed of sands 8 to 27 inches in thickness over a sandy loam layer approximately 18 inches thick over shelly materials about 24 inches thick. Materials underlying the shelly layer varied from clay to mixtures of sand, clay, gravel, and shell.

In order to obtain knowledge of the variability of the soil physical properties, each area was subdivided and samples were taken with an Uhland-type sampler (7). The soil cores (3 inches in diameter and 3 inches in height) were obtained at the surface, in the organic pan, and immediately below the organic pan in Leon, and at the surface and the upper and lower 3 inches of the sandy loam in the Felda. Total and noncapillary pore space, hydraulic conductivity, and bulk density were determined on each core sample.

Piezometers (⅜-inch iron pipe) were placed in the Leon sand to depths of 2, 3, and 4 feet at 25-foot intervals across the center of the 200-foot plot, 33-foot intervals across the 133-foot plot, and at 17-foot intervals across the 67-foot plot. On the Felda sand, piezometers were installed to depths of 2, 3, 4, 5, 6, 7, and 8 feet in 2 rows 180 feet apart across the central part of both plots. The groups of seven piezometers were placed 34 feet from the ditches and at intervals of 34 and 112 feet, in the 135- and 405-foot plots, respectively. At each location, 2 subirrigation and 2 drainage cycles were conducted by varying the elevation of water in the ditches. At various times during the cycles, hydraulic head measurements were obtained.

RESULTS AND DISCUSSION

The physical properties of the two soils are summarized in Table 1. The average values of the total samples collected from each layer of each soil type are reported here since most variation occurred between samples separated by short distances. The variation was not increased when samples were separated by great distances on each soil type. The terms "microheterogeneous" and "macrohomogeneous" have been suggested to describe this pattern of variation (2).

Both soil types are layered soils where the physical properties differ markedly within a profile and between profiles. The ratio of noncapillary porosities of the Felda sandy loam to the Leon organic pan was 0.16 while the total porosity of the sandy loam was only slightly less than that of the organic pan. Hydraulic conductivity is dependent upon the number and continuity of large pores. The conductivity of the Felda sandy loam was one tenth that of the Leon organic pan.

The elevation of the water tables midway between drains and the elevation of the ditch water in Leon plots during a representative subirrigation cycle are shown in Figure 1. The datum (top of piezometers) was an average of 3 inches above the soil surface. Subirrigation was begun December 1 following a month without rainfall. The average water table in the

TABLE 1.—PORE SPACE, HYDRAULIC CONDUCTIVITY AND BULK DENSITY OF VARIOUS PROFILE LAYERS IN LEON AND FELDA SOILS[1]

Soil series and layer of profile	Pore Space		Hydraulic conductivity	Bulk density
	Total	Noncapillary[2]		
	%	%	in/hr.	g./cc.
Leon surface	42.29	30.00	9.50	1.50
Leon organic pan	42.51	25.06	2.23	1.50
Leon below organic pan	38.39	24.50	6.41	1.67
Felda surface	40.48	20.55	13.90	1.54
Felda top 3″ s. lo.	40.79	4.25	0.23	1.62
Felda bottom 3″ s. lo.	37.60	3.68	0.18	1.69

[1]Average of 18 and 32 samples of Leon and Felda, respectively, with the exception of Felda surface where 10 samples were obtained.

[2]Calculated from moisture retention at a tension of 50 cm. of water for disturbed soil on Leon and soil cores on Felda.

area surrounding the plots was estimated to be about 3.5 feet below datum. During the first 24 hours, the water tables midway between ditches were raised 0.34, 1.06, and 1.45 feet in the 200-, 133-, and 67-foot plots, respectively. Thereafter, the rate of rise of the water table was less rapid and tended to fluctuate in the 67- and 133- foot plots with the inadequately controlled water level in the ditch. At 72 hours, the water tables were 2.9, 2.1, and 1.5 feet below the datum at the midpoint of the 200-, 133-, and 67-foot plots, respectively. Even after 9 days of subirrigation with no rainfall the water level at the midpoint of the 200-foot plot was still 0.84 foot lower than the ditch water. It would appear that water was escaping to the lower water table surrounding the plot area through slowly permeable layers deeper than 5 feet.

The elevations of water tables at the midpoints between drains and the elevation of ditch water for a drainage cycle beginning December 13 on Leon sand are shown in Figure 2. The water level in the ditches had been held at a high level (0.85 to 1.5 feet below datum) for 13 days and rainfall of 1.35 inches was recorded 2 days prior to the beginning of the cycle. Therefore, the water table in the area surrounding the plots was somewhat higher than during the subirrigation test which preceded this drainage cycle. During the first 24 hours, the water table in the 200-foot plot receded only 0.06 foot while in the 133- and 67-foot plots it had receded 0.78 and 1.01 feet, respectively. Between 42 and 74 hours after the beginning of the cycle, 0.95 inch of rainfall was recorded which returned the water table at the midpoint of the 200-foot plot to the same elevation as at the beginning of the cycle. The water tables in the remaining 2 plots were affected less. During a 46-hour period following the 72-hour observation point, the water table in the 200-foot plot receded 0.63 foot as compared to 0.19 foot in first 42 hours of the cycle. The difference in drainage rates may be attributed to the elliptical shape of the water table in the latter case as compared to an initially flat water table. Also, after the rainfall, the water table receded to some extent due to redistribution of water as the volume of entrapped air was reduced as a result of dissolution and escape (1).

The high ditch water level recorded at 120 hours had gradually built up due to pump failure at about 48 hours. The water level was dropped

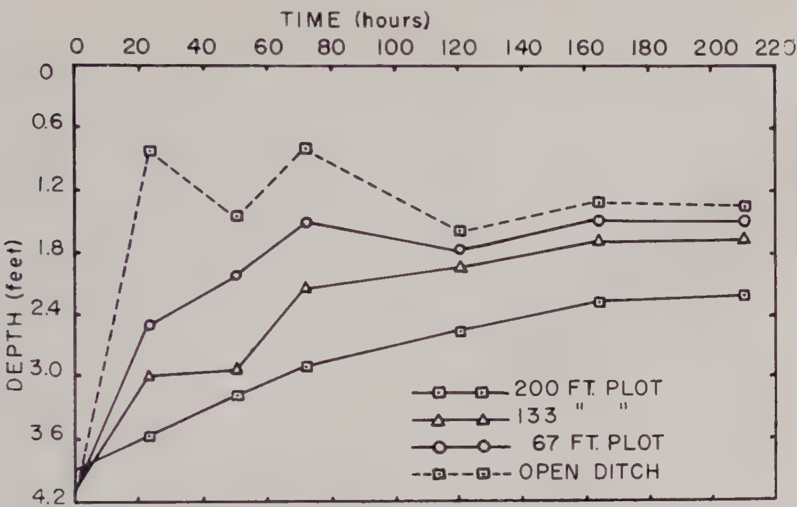

Fig. 1.—Water table elevations at the midpoint of three ditch spacings and ditch water elevations during a subirrigation cycle on Leon sand.

to about 4.1 feet within 4 hours after the 120-hour measurement. The increase in height of water table in the 200-foot plot at 190 hours was due to 0.25 inch of rainfall at about 180 hours. In general, the drainage cycle revealed about the same information as the subirrigation cycle except that an elliptical falling water table was observed in the drainage tests.

On the Felda plots, the water tables between ditches were nearly a straight line through the points where measurements were taken in both the 405- and 135-foot plots in contrast to the elliptical shape of the water

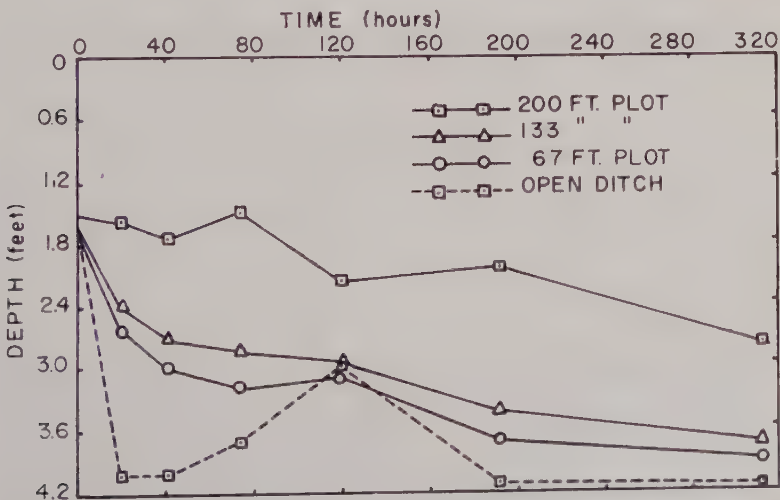

Fig. 2.—Water table elevations at the midpoint of three ditch spacings and ditch water elevations during a drainage cycle on Leon sand.

tables in Leon plots. Since the water tables were essentially flat, and because of the common distance from the ditch, the measuring stations 34 feet from the ditch separating the 135- and 405-foot plots were selected to show the fluctuations of the water tables in both drainage and subirrigation cycles. Similar results would have been obtained in a comparison of the elevation of water tables at the midpoint between ditches.

Elevations of the water tables (average of determinations from 2 groups of piezometers) for a representative subirrigation cycle are shown in Figure 3. The water tables and the ditch water had been low for an unknown period of time. The water tables were raised 0.7 and 0.8 foot in the 405- and 135-foot plots, respectively, during the first 22 hours while the ditch water was raised 2.6 feet. The 0.1 foot difference in elevations of the water tables in the two plots remained throughout the cycle and the water level in the ditch remained near 1.6 feet below datum. The water tables moved into the sandy loam very little during this time.

The contrast of water movement into the Leon and Felda was striking in several respects. There was virtually no ditch spacing effect on the Felda and the rise in the water table was initially rapid but nil after about 48 hours. Also the difference between the water table in the Felda and the ditch water remained almost constant at about 1.6 feet for 11 days after the first 2 days. These data, in the case of the Felda soil, reflect the effect of the highly permeable shell layer under the soil profile, the relatively slowly permeable sandy loam layer, and the lower water table in the areas surrounding the plots.

The water table elevations in the Felda plots during a drainage cycle are shown in Figure 4. Unfortunately, at the start of the experiment, differences in water tables in the 135- and 405-foot plots existed because surface drainage was good on the former plot and poor on the latter. The water levels were a result of events which occurred at 3, 2, and 1 days prior to the beginning of the cycle. These events were, respectively: water

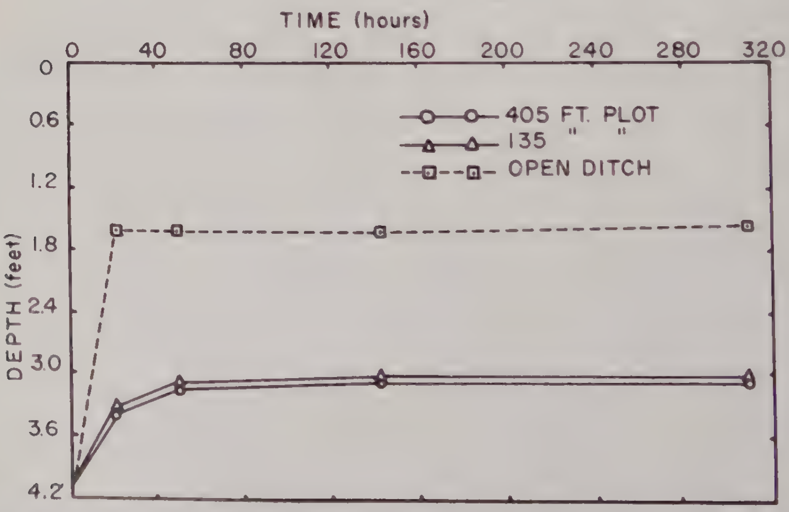

Fig. 3.—Water table elevations at 34 feet from a ditch in 135- and 405-foot plots and ditch water elevations during a subirrigation cycle on Felda sand.

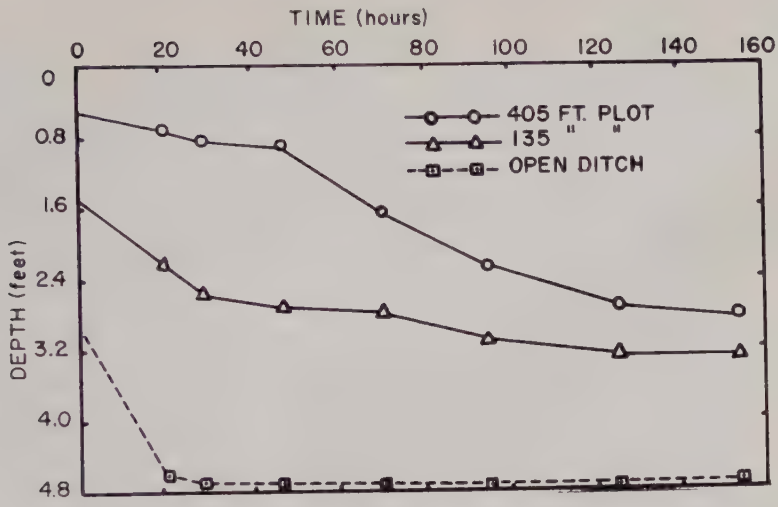

Fig. 4.—Water table elevations at 34 feet from a ditch in 135- and 405-foot plots and ditch water elevations during a drainage cycle on Felda sand.

pumped into ditches to 1 foot below datum; rainfall of 1.8 inches; and rainfall of 4.0 inches and water pumped from ditches to 3 feet below datum.

The experiment was begun with a lowering of the ditch water levels to 4.6 feet within 20 hours. The levels were maintained about 4.75 feet for the duration of the test. During the first 46 hours the water table in the 135-foot plot fell more rapidly than in the 405-foot plot due to the presence of ponded water on the latter. With the disappearance of the ponded water the relative rates of fall were reversed. Consequently, at the end of the cycle (153 hours) the water tables had fallen 2.28 and 1.78 feet in the 405- and 135-foot plots, respectively. It appears that the rate of fall of the water tables in the two plots would have been the same if they had started at the same levels.

In general, the drainage rate in the Felda was nearly as rapid as in the Leon. In both cases the rates of water table recession decreased with time. Important contributing factors include: decreasing hydraulic head differences with time; an increasing depth of profile to contribute water draining under tension as the water table falls; and the influence of the water table in areas adjacent to the plots.

SUMMARY AND CONCLUSIONS

Drainage plots with variable spaced open ditches were established on Leon and Felda sands. The influence of soil type, physical properties of the soil profile, and ditch spacings on the behavior of the water table during drainage and subirrigation was investigated. The falling water tables were elliptical in the Leon and flat in the Felda. There was a highly permeable shell layer under the slowly permeable sandy loam layer in the Felda in contrast to a slowly permeable layer underlying the Leon. Therefore, ditch spacings tended to influence water outflow and inflow very little on the

Felda and to a marked degree on the Leon. During subirrigation, the sandy loam layer in the Felda was penetrated only slightly during 13 days under a head of 1.5 feet of water. The organic pan in the Leon was more readily penetrated by the upward moving water table.

These findings indicate that where close control of the water table is desirable, ditches on Leon soil should be spaced approximately 133 feet. On Felda soil underlain by permeable shell or gravel, deep ditches spaced 405 feet or more should be adequate for subsurface drainage. Provision for surface drainage would be desirable on Leon soil and absolutely necessary on Felda soil for satisfactory water control.

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The Effects of Liming on the Availability of Fe and Mn and on Soil Ca and pH on Davie Fine Sand[1]

CHARLES C. HORTENSTINE AND H. Y. OZAKI[2]

Supplemental soil applications of Ca, as high calcic lime or dolomite, have benefited many crops in Florida. Robertson *et al* (7) reported the results of extensive liming trials in north and west Florida on corn, peanuts, soybeans, and oats grown on four soils over a period of 11 years. Yields of corn, peanuts, and soybeans were increased by the addition of 5,300 pounds per acre of dolomite to Red Bay fine sandy loam. Corn and peanuts responded to 8,000 pounds of dolomite per acre on Ruston fine sandy loam—soil pH was increased from 5.2 to 7.4. Applications of high calcic lime to Klej fine sand tripled peanut yields. Corn, peanut, and soybean yields were increased by applying 2,000 pounds per acre of dolomite to Norfolk loamy fine sand. Oat yields were not increased by lime additions to any of the above soils, and in some cases were actually reduced.

Forsee *et al* (3) increased yields of marketable tomatoes from 151 to 263 crates per acre by adding 1,000 pounds of hydrated lime per acre to an Immokalee fine sand. The pH increased from 4.75 to 6.56 in 3 months following incorporation of the lime into the soil.

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It is universally accepted that liming soils to a pH greater than 6.5 tends to decrease the availability of certain micronutrients, particularly Fe and Mn. Hall and Dennison (4) found less than 16 ppm. Mn in chlorotic strawberry leaves from plants growing in soil of pH 6.5 and above. A slight leaf chlorosis appeared with a Mn content of 20 to 64 ppm. from a soil with a pH between 5.9 and 6.3. There was no chlorosis in strawberry leaves containing 94 to 222 ppm. Mn from soil of pH value 5.1 to 5.3.

Fiskell (2) found a decrease in exchangeable and easily reducible Mn content in 5 fine sandy loam soils of west Florida, sampled 3 years following an application of 3,000 pounds per acre of dolomite. However, Hutton and Robertson (5) obtained no yield increases from any micronutrient applied to corn, peanuts, soybeans, or oats grown on these soils, whether lime was applied or not.

According to Kuykendall (6), Fe deficiency in citrus is widespread in Florida, especially in the more alkaline soils of the Indian River and upper East Coast areas. He found that chlorosis developed in citrus leaves containing less than 60 ppm. Fe.

The objectives of the experiment reported herein were to (1) evaluate the response of bush snap beans to lime on Davie fine sand, (2) compare the uptake of Fe, Mn, and Ca by bush beans from limed and unlimed soil, (3) evaluate new pelleted and pulverized sources of Fe and Mn, and (4) determine the changes in soil Ca and soil pH over a period of several months as the result of liming.

EXPERIMENTAL PROCEDURE

The soil used in this experiment was a Davie fine sand located on the Plantation Field Laboratory at Fort Lauderdale. High calcic lime was applied December 8, 1960, at rates of 0, 3000, 6000, and 9000 pounds per acre. Raised beds were prepared and fumigated with methyl dibromide December 12, 1960. Bush snap beans (Harvester var.) were planted January 5, 1961. Basic fertilizer was banded on each side of the seed at the rate of 65 pounds N, 23 pounds P, 70 pounds K, and 0.5 pound B per acre. A total of 60 pounds N and 50 pounds K per acre was applied as supplemental sidedressings. Compounds containing Fe and Mn were applied broadcast at planting time at the rate of 10 pounds per acre. The experimental design consisted of 5 treatments (powdered Fe or Mn, pelletized Fe or Mn, and a check) applied to each lime increment—a total of 20 treatments replicated 3 times.

Soil samples were taken from the 0 to 6-inch depth at the beginning of the experiment and at monthly intervals for a total of 8 sampling dates. The individual soil samples were analyzed in the Everglades Experiment Station Soil Test Laboratory for pH, P, K, Ca, and Mg. Values for pH were determined in a 1:1 soil to water ratio with the glass electrode on a Beckman Zeromatic pH meter. Phosphorus was determined colorimetrically as an ammonium molybdate complex on a water extract of the soil in a Cenco photelometer. The bases were determined on a 0.5 *N* HOAc soil extract in a Beckman DU flame photometer.

At harvest on March 1, 1961, 6 bean plants were collected at random from each plot and analyzed for Fe, Mn, and Ca contents. Plant material was dried at 70°C., ground in a stainless steel intermediate model Wiley mill to pass a 20-mesh screen, and wet ashed in an acid mixture of HNO_3 $-H_2SO_4-HClO_4$. Fe was reduced to the ferrous state with hydroxylamine

hydrochloride and determined as a ferrous complex of orthophenanthroline. Mn was determined as $HMnO_4$—a purple complex developed by the reaction of phosphoric acid (H_3PO_4—85%) and trisodium paraperiodate ($Na_3H_2IO_6$) with Mn^{++}. Calcium was determined by titration with Versene using Eriochrome black T as an indicator.

RESULTS AND DISCUSSION

The soil used in this experiment was low in fertility—pH 5.4, 3 pounds water-extractable P per acre, and HOAc-extractable bases of 7 pounds K, 370 pounds Ca, and 250 pounds Mg per acre. Calcium levels ranged from a low of 125 pounds per acre to a high of 1,000 pounds per acre among plots, but the other elements were fairly uniform through the plots.

Total bean pod yields from 2 harvests of 25-foot rows are presented in Table 1. Lime had a highly significant effect on yields, but only at the 3,000-pound per acre level. There was a significant quadratic regression and a highly significant cubic regression of yields on lime increments. The analysis of covariance technique was used to remove the effect of the variation in original Ca levels among plots. Therefore, the yields presented in Table 1 were adjusted to conform to the equation $Y = Y_o + .0029\ (X_o - X_t)$ where Y is adjusted yield, Y_o is actual yield of each plot, X_o is original Ca level of each plot, and X_t is the average original Ca level of all plots.

The oven-dry weights of 6 bean plants from each plot are presented in Table 2. Plant weights also were increased by the 3,000 pound per acre rate of lime. There was a highly significant cubic regression of plant weight on lime. However, effects of original soil Ca levels on plant weight were not significant.

It had been anticipated that Fe and Mn would have a beneficial effect on plant growth and yields, especially in the plots treated with the 9,000 pound rate of lime. However, there was no noticeable effect from Fe or Mn applied to the soil and deficiency symptoms did not appear in the bean foliage.

The Ca, Fe, and Mn contents of the bean plants are presented in Tables 3, 4, and 5, respectively. Surprisingly, differences between liming rates in Ca uptake were not significant, but there was a definite trend toward a linear increase as liming rates increased. The uptake of Fe was unaffected by lime or Fe treatment; however, there was a significant cubic

TABLE 1.—YIELDS OF BEAN PODS AS AFFECTED BY APPLICATIONS OF CA, FE, AND MN TO DAVIE FINE SAND.

Micronutrient applied	Lime applied (pounds/acre)				
	0	3000	6000	9000	Ave.
	lbs.	lbs.	lbs.	lbs.	lbs.
Fe (powder)	4.1	6.1	4.8	4.5	4.9
Fe (pellets)	4.2	5.9	5.0	5.6	5.2
Mn (powder)	3.7	6.7	3.7	5.7	5.0
Mn (pellets)	6.1	7.2	5.2	4.6	5.8
Check	5.2	6.3	4.4	5.3	5.3
Ave.	4.7	6.5	4.6	5.2	5.2

TABLE 2.—COMBINED WEIGHTS OF 6 BEAN PLANTS AS AFFECTED BY CA, FE, AND MN APPLIED TO DAVIE FINE SAND.

Micronutrient applied	Lime applied (pounds/acre)				
	0	3000	6000	9000	Ave.
	g.	g.	g.	g.	g.
Fe (powder)	16.6	22.6	16.4	16.6	18.2
Fe (pellets)	19.4	21.8	19.2	21.4	20.5
Mn (powder)	17.4	24.3	15.6	18.1	18.9
Mn (pellets)	20.5	22.3	23.5	20.1	21.7
Check	17.4	24.5	19.2	24.0	21.3
Ave.	18.2	23.5	18.8	20.2	20.1

TABLE 3.—EFFECTS OF CA, FE, AND MN APPLIED TO DAVIE FINE SAND ON UPTAKE OF CA BY BEAN PLANTS.

Micronutrient applied	Lime applied (pounds/acre)				
	0	3000	6000	9000	Ave.
	%	%	%	%	%
Fe (powder)	2.18	2.34	2.14	2.47	2.27
Fe (pellets)	1.94	1.84	2.48	2.07	2.10
Mn (powder)	2.84	2.33	2.75	2.44	2.60
Mn (pellets)	2.01	2.17	1.96	2.32	2.12
Check	2.10	2.63	2.30	2.93	2.47
Ave.	2.21	2.25	2.33	2.45	2.31

TABLE 4.—EFFECTS OF CA, FE, AND MN APPLIED TO DAVIE FINE SAND ON UPTAKE OF FE BY BEAN PLANTS.

Micronutrient applied	Lime applied (pounds/acre)				
	0	3000	6000	9000	Ave.
	ppm.	ppm.	ppm.	ppm.	ppm.
Fe (powder)	280	235	280	250	260
Fe (pellets)	320	220	270	215	255
Mn (powder)	300	235	320	280	285
Mn (pellets)	235	235	230	260	240
Check	265	275	240	255	260
Ave.	280	240	270	255	260

regression of Fe contents on lime rates and a significant difference in Fe uptake between the pulverized and pelletized forms of Mn applied. In contrast to Fe uptake, the addition of lime drastically reduced the uptake of Mn by the bean plants. Linear and cubic regressions of Mn content of plants on lime increments were highly significant and the quadratic regression was significant.

TABLE 5.—EFFECTS OF CA, FE, AND MN APPLIED TO DAVIE FINE SAND ON UPTAKE OF MN BY BEAN PLANTS.

Micronutrient applied	Lime applied (pounds/acre)				
	0	3000	6000	9000	Ave.
	ppm.	ppm.	ppm.	ppm.	ppm.
Fe (powder)	171	99	121	151	136
Fe (pellets)	181	110	107	60	114
Mn (powder)	162	91	162	107	130
Mn (pellets)	115	99	121	124	114
Check	159	113	132	115	130
Ave.	158	102	129	111	125

The lack of a significant response to lime in plant Ca content has been shown by Chambers and Gardner (1) who actually obtained a decrease in Ca uptake by beans grown in soil treated with 3,800 pounds of $CaCO_3$ per acre as compared to unlimed soil. Wheat, oats, barley, and peas in their tests reacted in much the same manner as beans. The small effect of liming on Ca uptake by bean plants in the present study does not rule out an effect of Ca on plant growth. The increased yields and weight of the plants in the presence of lime, particularly at the 3,000-pound per acre rate, attest to the need for added Ca in Davie fine sand.

As with Ca, plants frequently show no variation in Fe content—even under Fe deficiency conditions resulting in chlorotic leaves. One of the reasons for using the highest lime rate (9,000 pounds per acre) was to induce an Fe deficiency by decreasing the availability of the soil Fe. This objective was not achieved, at least to the extent of producing visual symptoms of Fe deficiency in the plants.

In contrast to Fe, the addition of lime decreased uptake of Mn by the bean plants. However, as indicated by plant appearance and Mn content, no immobilization of Mn was induced by the lime. Evidently, this soil was quite high in available Mn. The effect of applied Mn on Fe uptake is obscure, but it is generally accepted that an excess of Mn will cause a decrease in the availability of Fe through oxidation and vice versa.

Common to all of the measurements of plant response, except Ca uptake, one interesting facet was manifest. That was the significant cubic regression resulting from increasing increments of lime. There is no logical explanation for this at the present time.

SOIL REACTION

One of the main points in a good soil fertility management program is the maintenance of a favorable soil reaction, or pH. Generally, a pH between 6.0 and 6.5 is conducive to optimum growth of most plants. In Figure 1, the pH of the soil in this experiment is traced for a period of several months at each lime level. Differences among the 3,000-, 6,000-, and 9,000-pound rates were not significant; however, all applications resulted in a highly significant increase in pH above unlimed soil.

In contrast to the highly variable Ca content of the soil, there was little variation in pH among plots—coefficients of variation ranged from 2.79

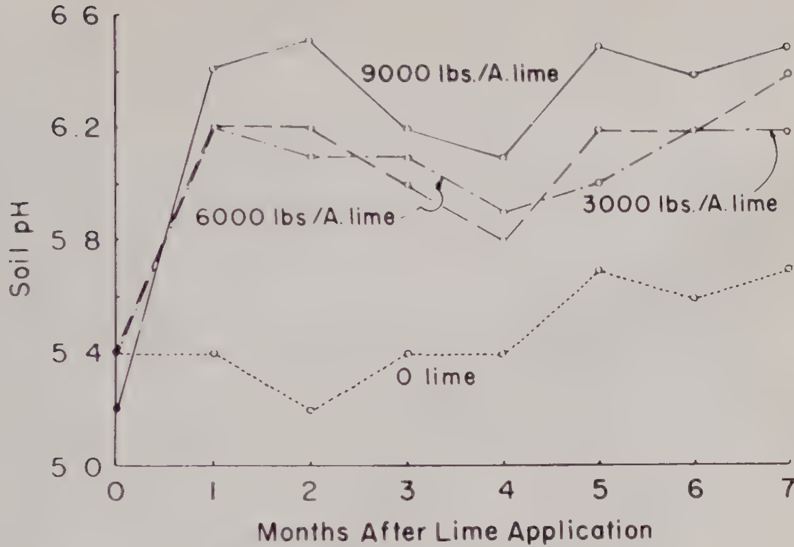

Fig. 1.—Effects of lime applied to Davie fine sand on soil pH.

to 6.22% for pH and 10.69 to 32.01% for Ca. The Ca levels of the soil are shown in Figure 2. The soil Ca content closely paralleled the soil pH.

It may safely be concluded for a soil of this type that 3,000 pounds of lime applied per acre will supply sufficient Ca for plant growth and provide a soil pH close to the optimum.

ACKNOWLEDGMENTS

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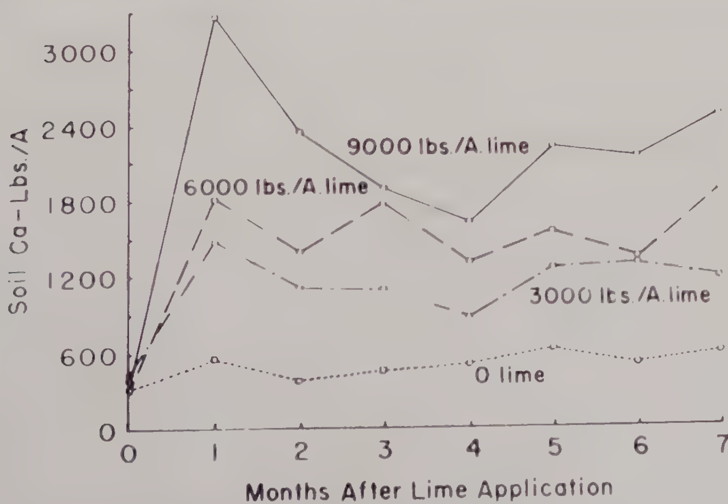

Fig. 2.—Effects of lime applied to Davie fine sand on soil Ca content.

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Effect of Lime on Yield of Peppers and on Soil Calcium[1]

H. Y. OZAKI AND C. C. HORTENSTINE[2]

More than 9,000 acres of peppers were planted on the sandy soils of the lower east coast during the 1958 season (6). Most of the acreage was planted for winter and early spring harvests when production from other parts of the United States is low.

Forsee, *et al.* (2) reported that peppers on these soils usually responded to lime. However, no intensive studies were conducted to determine quantity of lime required. Four experiments were conducted to determine the effect of lime and soil Ca levels on pepper yields.

MATERIALS AND METHODS

Experiments were conducted at Plantation Field Laboratory on Davie fine sand which had been cropped to vegetables for 2 to 4 years. The water table was maintained at 2 to 3 feet by subsurface irrigation. Bed type culture was used to provide field drainage during periods of heavy rainfall.

In the 1955 experiment, 400 mesh hydrated lime with an analysis of 96% CaO was applied. Agricultural limestone with an analysis of 97% $CaCO_3$ (dry basis) 50% passing 60 mesh sieve, 80% passing 20 mesh sieve, not more than 10% moisture, was used in the three experiments conducted from 1958 through 1960. Lime was broadcast and disked-in two weeks prior to bedding.

Each year 26 to 44 pounds of P per acre were applied in 1 or 2 applications of complete fertilizer. In addition, 300 to 350 pounds of N and 258

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to 282 pounds of K per acre were applied in the complete fertilizer and in 9 or 10 nitrogen-potash sidedressings. Magnesium, copper, manganese, zinc, boron, and iron were also applied each year.

Florida Giant peppers were grown on 68-inch beds. Two rows were planted on each bed, 16 inches apart. Plants were thinned to a 9-inch spacing in the row. Except for the 1960 experiment, each plot consisted of 4 rows, 27 feet long. A guard bed was planted between plots. Sections 25 feet in length were harvested from the experiments conducted from 1955 through 1959, and 12.5-foot sections were harvested from the 1960 experiment. Pod yields were subjected to the analysis of variance (1) and to to single degree of freedom analysis. (4).

Ten borings per soil sample were taken at a 6-inch depth from each plot, except in the 1955 experiment, in which only 5 borings per sample were taken from each of the 4 replications before liming. Samples for 1958 to 1960 experiments were from the leveled soil surface before liming and also from the beds during the growing season. Samples from the 1958 experiment were from top of beds, and samples for the 1959 and 1960 experiments were from shoulders of beds.

Determinations of pH and Ca were made at Everglades Experiment Station Soils Testing Laboratory. Calcium was determined in a 0.5 *N* HOAc extraction in a Beckman Du flame photometer, and pH was determined in a 1:1 soil:water suspension with the glass electrode on a Beckman Zeromatic pH meter.

EXPERIMENTAL PROCEDURE AND RESULTS

1955 Experiment

Treatments of 0, 2,000 and 4,000 pounds of hydrated lime per acre were applied to soil that had a pH of 4.9 and 400 pounds of acid soluble Ca per acre. Each lime treatment was replicated 12 times.

Pepper seeds were field sown on November 10, 1955. The first harvest was made on March 15, 1956, and the last of 8 harvests was made on April 26.

Lime treatments did not significantly affect yields of total or marketable (U.S. fancy + U. S. No. 1) peppers, but effect of 4,000 pounds of lime was a highly significant decrease in number of blossom-end rot fruits (Table 1).

1958 Experiment

Treatments of 0, 500, 1,000, and 2,000 pounds of agricultural limestone per acre were broadcast and disked-in on September 26, 1958, in soil con-

TABLE 1.—EFFECT OF LIMING ON YIELD OF PEPPERS FROM DAVIE FINE SAND CONTAINING 400 POUNDS OF CA PER ACRE PRIOR TO LIMING, 1955 EXPERIMENT.

Hydrated Lime (lbs./A.)	Yield (Bu./Acre) Total	Marketable	Blossom-end Rot (No./Acre)
0	790	598	4,923
2,000	865	621	3,938
4,000	905	666	2,246
Significance	N.S.	N.S.	Linear**

TABLE 2.—EFFECT OF LIMING ON YIELD OF PEPPERS FROM DAVIE FINE SAND CONTAINING 240 POUNDS OF CA PER ACRE PRIOR TO LIMING, 1958 EXPERIMENT.

Lime (lbs./A.) Agricultural	Yield (Bu./Acre) Total	Marketable
0	550	315
500	675	401
1,000	685	402
2,000	675	431
Significance	Linear** Quadratic*	Linear**

taining 240 pounds of acid soluble Ca per acre with a pH of 4.9. Pepper seeds were sown in the plots, replicated 6 times, on October 13, 1958. The first harvest was made on February 2, 1959, and the last of 7 harvests was made on April 27.

The lime treatments resulted in highly significant yield increases when compared to the check (Table 2). Although the 1,000-pound lime treatment plots produced the highest total yield, the 2,000-pound treatment plots produced the highest marketable (U. S. fancy + U. S. No. 1) yield.

The 2,000-pound lime treatment increased soil Ca to 580 pounds per acre in six months (Figure 1). The increase was 330 pounds above the Ca level before liming. Although the 500-pound treatment increased the Ca level only 3 pounds, the 1,000-pound treatment increased the level 50 pounds. The changes in Ca level were also indicated by pH's of 4.5, 4.6, 5.0 and 5.4 for the check, 500-, 1,000-, and 2,000-pound lime treatments, respectively, after termination of the experiment in May.

One year after application, the 2,000-pound lime treatment resulted in the highest soil Ca level of 480 pounds per acre (Figure 1). Although the Ca level of the 2,000-pound treatment was lower at one year than at six months, the levels of the check, 500- and 1,000-pound lime treatments at one year increased above the six month levels (Figure 1). The Ca differences were indicated also by pH's of 4.6, 4.7, 4.9, and 5.1 for check, 500-, 1,000-, and 2,000-pound treatments, respectively, one year after application.

1959 Experiment

The plots of the 1958 experiment were relimed with 0, 500, 1,000, and 2,000 pounds of agricultural limestone per acre one year after the first application. Pepper seeds were sown on November 24, 1959. A 28-degree frost on January 21, 1960, injured the young tender foliage. In addition, the plants suffered at times from lack of irrigation in March, April, and May. The first harvest was made on February 26, 1960, and the last of 4 harvests was made on May 31, 1960.

The 2,000-pound lime treatment, which produced the largest plants, resulted in highly significant yield increases above the yields from 0, 500-, and 1,000- pound lime treatments (Table 3).

Although neither the 500- nor 1,000-pound lime treatment increased the soil Ca level at the termination of the experiment in May, 1960, above the level prior to the second application of lime, the 2,000-pound lime treatment per acre increased the Ca level from 480 to 515 pounds per acre (Figure 1). The Ca level of the check plots dropped to 205 pounds per acre. The differences in soil Ca were shown also by the average pH's of

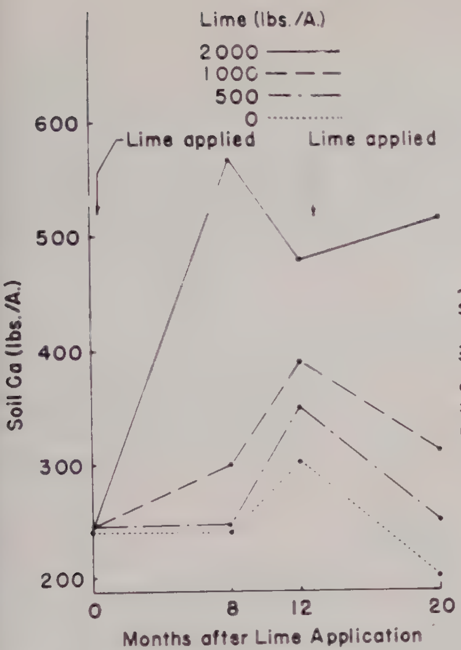

Fig. 1.—Effect of liming on acid soluble soil calcium of Davie fine sand at termination of 2 growing seasons.

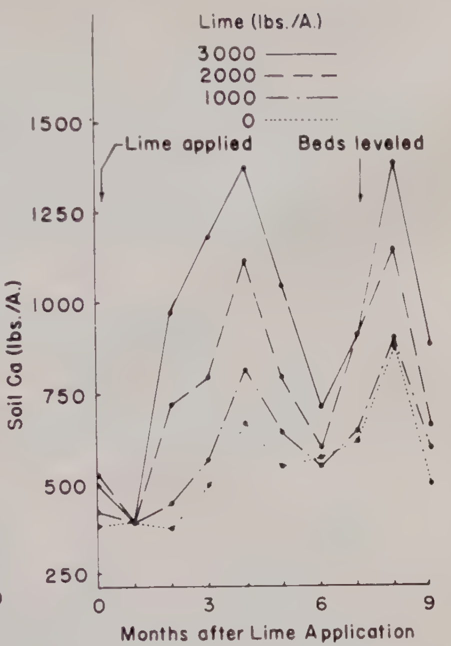

Fig. 2.—Effect of 4 lime treatments on monthly acid soluble soil calcium of Davie fine sand, 1960 pepper experiment.

4.7, 4.8, 5.1, and 5.5 for check, 500-, 1,000-, and 2,000-pound lime treatments, respectively, at the termination of the experiment.

1960 Experiment

The experiment was on soil with 450 pounds acid soluble Ca per acre and pH 5.6 before liming. Treatments of 0, 1,000, 2,000 and 3,000 pounds of agricultural limestone per acre were broadcast and disked-in on November 7, 1960. The treatments were replicated 8 times.

Pepper seeds were field sown on December 8, 1960. The first harvest was made on April 10 and the last of 6 harvests on May 29, 1961.

Limestone treatments did not significantly increase pod yields over the check yield (Table 4).

TABLE 3.—EFFECT OF LIMING ON SECOND SEASON YIELD OF PEPPERS FROM PLOTS LIMED FOR TWO SUCCESSIVE YEARS, 1959 EXPERIMENT.

Agricultural Lime (lbs./A.)	Yield (Bu./Acre) Total	Marketable
0	195	40
500	240	79
1,000	285	106
2,000	425	211
Significance	Linear**	Linear**

Although the monthly Ca levels fluctuated during the growing season, the 3,000-pound lime treatment resulted in the highest Ca level—over 1300 pounds per acre at the fourth and eighth samplings after application. The soil Ca levels of all treatments, including check, increased to high levels four months after lime applications (Figure 2). The levels dropped during the fifth and sixth months. The Ca levels increased during the early months of fallowing. They increased to high levels eight months after application and dropped after the ninth month (Figure 2). The pH values were 5.8, 5.7, 6.3, and 6.5 at 4 months, and 5.8, 6.0, 5.9, and 6.0 at 8 months for 0, 1,000-, 2,000-, and 3,000-pound treatments, respectively.

TABLE 4.—EFFECT OF LIMING ON YIELD OF PEPPERS FROM PLOTS CONTAINING 450 POUNDS OF CA PER ACRE PRIOR TO LIMING, 1960 EXPERIMENT.

Agricultural Lime (lbs./A.)	Yield (Bu./Acre) Total	Marketable
0	1,160	830
1,000	1,130	855
2,000	1,190	885
3,000	1,090	800
Significance	N.S.	N.S.

DISCUSSION

Marketable pepper yields from 1958 plots with 570 pounds of soil calcium per acre at termination of the experiment were higher than yields from check plots with 240 pounds. Yields from 1959 plots with 520 pounds of soil calcium at termination of the experiment were higher than yields from plots with less than 300 pounds. In the 1960 experiment, yields from plots with 1100 pounds of soil calcium at the fourth month of the growing season and 600 pounds at termination of the experiment were not significantly higher than the yields from check plots with 650 pounds and 570 pounds, respectively.

Hayslip *et al.* (3) stated that the acid soluble soil Ca level should be above 400 pounds per acre for high yields of tomatoes. Probably this explains the lack of response of peppers to lime in 1955 and 1960 experiments.

In addition to soil sample variations and fertilizer applications, the increase in Ca levels of the check plots at times may have been due in part to surface drainage water during heavy rains carrying calcium to the check plots. Part of the increase of soil Ca levels of the unlimed plots may have also been due in part to the Ca content of the irrigation water, which varied from 40 to 80 ppm (5). During dry weather, the evaporation of water would tend to concentrate the Ca in the upper few inches of the soil.

Although the soil Ca levels in February samples increased after 1.1 and 1.9 inches of rain, which fell on January 9 and 12, 1961, respectively, the Ca level of all plots decreased in samples taken 3 days after a 1.9 inch rain on April 1. Following 1.1 and 2.0 inches of rain on June 9 and June 28, the soil Ca levels of July samples taken from the levelled, fallow plots increased over June levels. However, following a 1.0 inch rain in July, the August Ca levels decreased from the July levels. The results show that monthly soil Ca levels were not always decreased by rains.

SUMMARY

Liming resulted in significant pepper yield increases only when the acid soluble soil Ca level was below 300 pounds per acre. The 2,000-pound agricultural limestone per acre treatment resulted, in general, in the highest yield of marketable (U. S. fancy + U. S. No. 1) peppers.

The treatment of 3,000 pounds of agricultural limestone per acre increased the acid soluble soil Ca levels during the growing season over the levels of lower rates of liming.

ACKNOWLEDGMENTS

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Late Summer Fertilization for Winter Forage in North Florida[1]

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Inadequate, low quality winter forage has been one of the major problems of the beef cattle industry in Florida. In recent years some improvement has resulted from the use of white clover in grass pastures on adapted soils; deferred grazing, whereby grass forage is accumulated in the field for the winter; and the preservation of excess summer forage as ensilage or hay. White clover has been very valuable in supplying forage during the early spring and in supplying substantial quantities of nitrogen for summer grass production. Deferred grazing is widely used but limited attention has been given to grass fertilization specifically for this purpose and the winter forage is frequently of extremely poor quality. Ensilage for beef cattle is in relatively limited use and hay making during the summer months has proved to be extremely unreliable. Artificial drying of forage for beef cattle is a questionable economic practice.

Because of the continued winter forage deficit, late summer and fall grass forage production for hay making during the period, October to December, particularly in northern Florida, appeared to offer possibilities. Alternately, forage produced during this period could be used for deferred winter grazing if circumstances demanded. Weather data showed that October and November are months of relatively low rainfall. The prediction of rain during this period is also more accurate than during the summer months when local showers are frequent. According to Butson (4) the chance of having a week with no more than 0.5 inch of precipitation is almost 75 percent from the latter part of October through November 28. In contrast, during July and August the chance of having no more than 0.5 inch in a given week is less than 25 percent.

For several years it was observed that the growth rate of the common perennial grasses was drastically retarded during the latter part of September and October in northern Florida. Response to fertilizer was very limited if applied at this time. Minimum night temperatures usually declined about the middle of September from about 70 F. for the summer months to a range of 60 to 70°. McCloud *et al* (6) showed that by artificially decreasing night temperatures from 70° to 60°, the growth rate of pangola and Coastal bermuda grasses was decreased by 20%. Growth rate was further decreased by 10 to 15% by reducing the night temperatures to 50°. The production of large yields of high quality forage for processing or grazing during the fall and winter obviously requires fertilization for growth during the favorable period prior to the time when temperature becomes limiting.

This report is concerned with the effects of timing and rates of nitrogen fertilization on the production of optimum yields of quality forage in the fall and the maintenance of forage quality through the winter months.

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EXPERIMENTAL METHODS

Field studies were conducted from 1955 through 1958 at Gainesville, and the Suwannee Valley Station, Live Oak. In 1955 the responses to rates of nitrogen from 0 to 150 pounds per acre with adequate levels of phosphate and potash in a 1 to 2 ratio were studied. During the remaining years the maximum nitrogen level was 100 pounds per acre because of severe lodging of the grasses and deterioration of the stand of pangolagrass which took place at higher rates. Subsequently, studies of the effect of fertilization dates on forage yields, quality and nitrogen effciency were made. Animal feeding studies as well as chemical analysis were used to evaluate forages. The effect of weathering on forage quality was determined during two years by taking forage samples periodically during the winter season from differentially treated plots.

Nitrogen for all experiments was applied as ammonium nitrate. Forage yields are expressed as oven-dry weights (70°C). Nitrogen, phosphorus, potassium and calcium were determined by conventional methods (3). Total nitrogen was multiplied by 6.25 to convert it to total protein.

The percentage utilization of applied nitrogen was calculated by subtracting the total nitrogen contained in forage from untreated plots from the nitrogen in forage from treated plots. Control plots were mowed at approximately the same time as treated plots.

RESULTS AND DISCUSSION

Yields and protein contents increased with nitrogen application through the highest rates applied in the initial nitrogen rate study, Table 1. The forage was cut 1 inch above ground with a sickle-bar mower just prior to

TABLE 1.—THE EFFECT OF LATE SUMMER FERTILIZATION ON OVEN-DRY YIELDS AND PROTEIN CONTENTS OF GRASS FORAGES.

Nitrogen[1] Applied lbs/A.	Pangolagrass (Gainesville) Forage lbs/A.	Pangolagrass (Gainesville) Protein %	Argentine Bahiagrass (Gainesville) Forage lbs/A.	Argentine Bahiagrass (Gainesville) Protein %	Coastal Bermudagrass (Suwannee Valley Station) Forage lbs/A.	Coastal Bermudagrass (Suwannee Valley Station) Protein %
			1955			
0	2470	5.5	--------	----	2020	5.3
25	3710	5.8	--------	----	3080	6.9
50	4130	7.3	--------	----	3370	7.2
100	4880	8.7	--------	----	3880	8.7
150	5340	10.0	--------	----	4340	9.7
			1956			
0	360	4.5	200	4.8	590	5.6
25	1140	4.4	340	5.2	1500	6.7
50	2100	4.9	910	5.9	2100	6.6
75	2800	5.5	1190	6.2	2420	8.3
100	3310	6.2	1710	7.6	2870	9.6

[1]In 1955 the nitrogen was applied at Gainesville on September 7 and at the Suwannee Valley Station on September 9; in 1956 applications were made on August 27 at Gainesville and August 29 at the Suwannee Valley Station. Harvests were made on October 17-19, 1955 and November 5, 1956.

fertilization about September 1. Because of the short interval between fertilization and harvest, forage was relatively young when harvested and therefore the check treatments contained more protein than is typical for grass harvested at the same season on farms and ranches (5).

Yield and protein increases were obtained through 150 pounds of nitrogen per acre. However, very good quality forage was produced by application of 100 pounds per acre and because of the increased possibility of lodging with higher rates, no more than 100 pounds is justified. If the forage were to be left in the field for grazing a compromise between yield and quality, and resistance to lodging would be necessary. For deferred grazing it appears that about 75 pounds of nitrogen per acre would incorporate the optimum of yield, quality and efficiency of forage utilization by grazing animals.

Pangola and Coastal bermudagrasses were more responsive to fertilization than the bahiagrasses. But due to the susceptibility of pangolagrass to cold damage, its use in north Florida for this purpose is limited.

Yield and protein data for three years resulting from fertilizer applications beginning the latter part of August and continuing through September are shown in Table 2. Frequently yields and protein contents were lower in grasses fertilized in August than early September. This result was attributed to leaching of part of the applied nitrogen by intense rains shortly after fertilization. Maximum yields occurred from the September 1 fertilization, after which there was a gradual decline. In contrast, percentage protein generally increased as fertilization was delayed. While the highest yields resulted from fertilization about September 1, there was considerable variation in the dry weight produced for the same fertilization date from year to year. This would be expected from usual variations in growing conditions.

The percentage of applied nitrogen recovered in the forage, Table 3, was relatively low at all fertilization dates. In general, the maximum recovery occurred where fertilizer was applied about September 1. In spite of the low nitrogen recovery the application of nitrogen could usually be justified solely by the protein produced. Fertilization on approximately September 1 appears to be the optimum for forage yields, protein contents and nitrogen utilization efficiency. An attempt was made to increase the percentage of applied nitrogen recovered in forage by fertilizing in late July or early August to stimulate the plants into a more active state of growth prior to the regular late summer fertilization in September. Fifty pounds of nitrogen per acre were applied in this manner to half the experimental plots in 1957 and 1958. The grasses responded favorably to this nitrogen application, but response to the regular late-summer fertilization was essentially the same regardless of pretreatment. All plots were cut with a sickle bar mower immediately before late-summer fertilization. An attempt to improve nitrogen recovery from late-summer fertilization by fertilizing plots which have been mowed two weeks or more before nitrogen is applied is in progress. It is hoped that greater leaf surface and forage volume will provide a reservoir for rapid nitrogen absorption and, thereby, greater efficiency.

Field and laboratory results were supplemented by animal feeding trials with open yearling heifers using hay from two harvest dates and two rates of fertilization (1, 2). A Coastal bermudagrass pasture was fertilized just prior to September 1 with 50 and 100 pounds of nitrogen per acre. In addition five hundred pounds of 0-10-20 per acre were applied uniformly

TABLE 2.—THE EFFECT OF TIME OF LATE SUMMER FERTILIZATION[1] ON OVEN-DRY YIELDS AND PROTEIN CONTENTS OF GRASS FORAGES.

Dates of[2] Fertilization	Pangolagrass (Gainesville)		Argentine Bahiagrass (Gainesville)		Coastal Bermudagrass (Suwannee Valley Station)	
	Yield lbs/A	Protein %	Yield lbs/A	Protein %	Yield lbs/A	Protein %
			1956			
8/27	4230	5.1	1770	8.0	2920	7.5
8/30	3250	4.5	1550	8.3	3370	9.2
9/3	2880	4.7	1280	8.6	2880	9.4
9/6	4240	6.1	1090	8.6	2120	10.2
9/10	4470	6.8	770	10.4	1040	11.9
9/15	3280	8.1	650	10.9	1120	12.8
9/18	3170	7.9	740	11.3	1070	12.5
9/21	3440	8.7	420	12.2	1130	11.9
			1957			
8/23	1520	8.8	1780	8.4[4]	3870	6.1
8/28	2080	7.7	2010	8.4	4140	6.4
9/2	2330	8.8	1670	7.6	3700	7.6
9/6	1730	8.9	1400	8.6	2490	9.4
9/12	2210	6.5	1390	9.3	2170	8.7
9/17	1210	7.6	1250	9.6	1500	11.3
9/24	1390	10.8	880	12.3	500	14.8
10/1	900	14.0	800	11.3	70	7.2
			1958			
8/26	2200	7.8[3]	1630	8.2[4]	2060	7.5
9/2	2320	8.8	1390	7.9	1920	7.8
9/9	2160	9.4	960	9.3	1500	9.9
9/16	1650	9.9	970	11.1	670	11.6
9/23	1040	8.9	540	10.6	180	11.5
9/30	910	11.0	440	11.8	50	10.5

[1]Nitrogen was applied at 75 pounds per acre and 0-10-20 at 300 pounds per acre.
[2]*Harvest Dates*
Gainesville:
Pangolagrass 11/1/56 & 11/4/57
Coastal Bermudagrass 11/13/58
Argentine Bahiagrass 11/ 5/56
Pensacola Bahiagrass 11/ 4/57 & 11/13/58
Suwannee Valley Station:
Coastal Bermudagrass 11/ 5/56, 10/28/57, & 10/27/58
[3]Coastal Bermudagrass
[4]Pensacola Bahiagrass

to avoid possible phosphate and potash deficiencies. Hay was harvested from half of each treatment in October and from the other half in early December after the first killing frost. The hays constituted the only protein and energy source. Chemical analysis showed the total protein content to be lower for the lower rate of nitrogen and for the December harvest, Table 4. Digestion trials with heifers showed the protein to be substantially less digestible for the December harvest. Adequate gains for this class of animal were obtained from all lots except the 50-pound rate harvested in December. Substantial weight losses occurred with this lot. However, even the poorest forage produced in the experiment would have maintained an animal through the winter with less weight loss than frequently occurs on Florida's ranches.

TABLE 3.—EFFICIENCY OF NITROGEN UTILIZATION BY FORAGE PLANTS AS AFFECTED BY DATES OF FERTILIZATION.

Dates of[1] Fertilization	Pensacola Bahiagrass (Gainesville)	Coastal Bermudagrass (Gainesville)	Coastal Bermudagrass (Suwannee Valley Station)
	Percentage of Applied Nitrogen Recovered in Forage		
	1957		
8/23	12.4	----	38.4
8/28	14.9	----	44.2
9/2	5.6	----	48.2
9/6	4.7	----	37.8
9/12	12.4	----	34.4
9/17	10.6	----	29.9
9/24	8.7	----	14.7
10/1	7.3	----	0
	1958		
8/26	18.0	18.2	25.7
9/2	15.1	27.0	23.9
9/9	10.1	34.6	25.6
9/16	17.3	25.2	14.4
9/23	6.7	9.3	3.2
9/30	6.1	13.5	0

[1]Nitrogen applied at 75 pounds per acre and 0-10-20 at 300 pounds per acre.

Grass hay, produced in Florida, has usually been of low protein content, and grass forage left in the field for winter grazing is frequently of low quality. It has been suggested that the quality of frosted forage left standing in the field decreases rapidly from weathering. Data in Table 5 show the effects of weathering on three grasses during two years of widely different rainfall. Rainfall at Gainesville between October 17, 1955 and February 19, 1956 was 9.61 inches. It was only 0.67 inches between November 1, 1956 and January 22, 1957. The 51-year averages for the two intervals are 11.48 and 7.09 inches, respectively. At Live Oak, rainfall was 9.83 inches between October 18, 1955 and February 19, 1956, and only 1.07 inches between November 5, 1956 and January 23, 1957. In both years the potassium in the plant was reduced to very low levels by weathering but concentra-

TABLE 4.—TOTAL PROTEIN AND DIGESTIBLE PROTEIN IN COASTAL BERMUDAGRASS HAYS, AND DAILY WEIGHT GAINS OF HEIFERS CONSUMING THE HAYS.

Nitrogen Applied	Harvest Date	Total Protein	Digestible[1] Protein	Average Daily Gain
lbs/A		%	%	lbs.
100	October 28, 1957	8.93	5.00	0.7
50	October 28, 1957	6.81	3.20	0.6
100	December 9, 1957	6.68	3.71	0.4
50	December 9, 1957	4.97	1.60	−0.7

Condensed from Alexander *et al.* (2).
[1]The National Research Council reports that the digestible protein requirement for growth of yearling heifers is 0.8 pound per day.

TABLE 5.—THE EFFECT OF WINTER WEATHERING ON NUTRIENT LEVELS IN GRASS FORAGES.

Nitrogen[1] Applied	Pangolagrass (Gainesville)				Argentine Bahiagrass (Gainesville)				Coastal Bermudagrass (Suwannee Valley Station)			
	N	P	K	Ca	N	P	K	Ca	N	P	K	Ca
lbs/A.	%	%	%	%	%	%	%	%	%	%	%	%
						1955-56						
		10/17								10/18		
0	0.88	0.20	1.52	0.52	Bahiagrass not introduced into test until fall of 1956.				0.85	0.14	1.02	0.19
50	1.17	0.21	1.69	0.58					1.15	0.13	1.25	0.19
100	1.60	0.18	1.64	0.68					1.55	0.15	1.45	0.20
		12/7								12/8		
0	0.64	0.12	0.79	0.39					0.61	0.09	0.51	0.24
50	0.76	0.14	0.84	0.35					0.85	0.08	0.69	0.19
100	1.26	0.11	1.05	0.53					1.13	0.10	0.77	0.20
		1/18								1/19		
0	0.78	0.05	0.14	0.29					0.58	0.05	0.12	0.18
50	0.89	0.05	0.12	0.27					0.82	0.04	0.17	0.15
100	1.31	0.05	0.25	0.33					1.15	0.05	0.21	0.17
		2/20								2/20		
0	0.76	0.08	0.19	0.44					0.70	0.08	0.15	0.20
50	0.89	0.09	0.25	0.38					0.83	0.07	0.19	0.21
100	1.28	0.08	0.28	0.37					1.26	0.09	0.17	0.20
						1956-57						
		11/2				11/2				11/2		
0	0.89	0.23	1.23	0.27	0.76	0.15	0.81	0.42	0.72	0.16	0.70	0.25
50	1.06	0.21	1.78	0.22	0.95	0.16	1.12	0.37	0.78	0.13	0.97	0.28
100	1.53	0.22	2.04	0.30	1.22	0.17	1.38	0.38	0.99	0.14	1.07	0.27
		12/10				12/10				12/9		
0	0.99	0.22	1.09	0.28	0.61	0.11	0.64	0.45	0.68	0.12	0.31	0.18
50	0.84	0.19	1.47	0.22	0.91	0.13	1.21	0.43	0.73	0.11	0.51	0.21
100	1.53	0.18	1.81	0.29	1.06	0.13	1.20	0.42	0.90	0.11	0.62	0.22
		1/23				1/23				1/21		
0	0.98	0.14	0.47	0.39	0.69	0.08	0.17	0.42	0.69	0.10	0.16	0.14
50	0.90	0.15	0.78	0.18	0.95	0.11	0.45	0.43	0.67	0.09	0.33	0.13
100	1.36	0.13	0.62	0.26	1.28	0.13	0.67	0.42	0.96	0.12	0.41	0.13

[1]In 1955 fertilizer was applied at Gainesville on September 7, and at the Suwannee Valley Station on September 9; in 1956 fertilizer was applied at Gainesville on August 27 and at the Suwannee Valley Station on August 29. Fertilizer included nitrogen, at the rates shown, and 300 pounds of 0-10-20 per acre.

tions of phosphorus and calcium were less affected. Lowest levels were observed in the year of highest rainfall. Protein, which is one of the most critical constituents of forage, was reduced only slightly by weathering. As with the mineral content more protein was lost during the wettest year. It is evident that low quality winter forage begins with forage of low protein content in the fall, a condition readily corrected by proper late-summer fertilization.

SUMMARY

The optimum combination of yield, total protein content and protein production per acre for fall hay making or deferred grazing was obtained with perennial grass pastures in the North and North Central Florida area when fertilized with nitrogen about September 1. Earlier fertilization resulted in a low protein forage while later fertilization resulted in marked yield reduction. Even though higher percentage protein was obtained at fertilization dates after September 1, total protein production was reduced. One hundred pounds of nitrogen per acre gave near optimum yields of forage with a satisfactory protein content. Higher rates resulted in severe forage lodging during the winter months without giving a large yield increase. Seventy-five pounds per acre will probably be more satisfactory if forage is to be left in the field for grazing in order to reduce lodging and the resulting loss of palatability. Chemical analysis and digestion trials showed some decline in total protein content and a larger decline in digestible protein of December-harvested forage when compared with late October harvest. Growth of yearling heifers confirmed forage quality as estimated from chemical analysis and digestion trials.

Weathering of forage from November through January had little effect on protein contents during two seasons of widely different rainfall. The potash contents were greatly reduced in both years: phosphorus and calcium concentrations were less affected.

The reduced growth rate of perennial grasses after the middle of September permits fertilization for a protein level which will insure a quality forage for hay or deferred grazing.

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The Response of Pangolagrass to Nitrogen from Several Sources[1]

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Pangolagrass (*Digitaria decumbens* stent.) was introduced into Florida during the 1930's and released to farmers in Florida in 1943. This new grass proved to be adapted particularly to the mineral soils of peninsular Florida south of a line generally drawn from Ocala through Orlando. Wallace *et al* (6) reported that approximately 500,000 acres were planted to this species by 1955.

Although research workers have conducted fertility experiments with Pangola, its response to nitrogen derived from several sources, applied as a solution or in dry form, has not been fully determined under the climatic conditions prevailing in its area of greatest adaptability. It was with this in mind that a trial involving sources of nitrogen was planned, including, insofar as practicable, the dates and rates of application of major fertilizer elements used on pastures in peninsular Florida.

Volk (5) reports that the carriers of nitrogen available for use as fertilizer materials in agriculture has not changed since the introduction of urea, anhydrous ammonia and ammonium nitrate in forms suitable for practical usage. However, there has been considerable change in the methods through which these materials are employed. He also states that the differential response of a given crop to different forms of nitrogen is not primarily a response to that form of nitrogen, but rather a reflection of the effect of soil and other environmental factors on the rates of transformation from one form of nitrogen to another.

The objectives of this trial were to determine the response of pangolagrass in relation to: (1) tons of air-dry forage per acre; (2) percent crude protein in herbage; (3) total pounds of nitrogen recovered and (4) comparison of yields of grass produced on 3 base treatments of P_2O_5 and K_2O.

EXPERIMENTAL PROCEDURE

The experiments were conducted on a uniform stand of Pangola at the Range Cattle Station, Ona, Florida. The sod was approximately 10 years old when the trials started and had received no fertilizer applications since spring 1954. Soil type was Immokalee fine sand with an initial pH of 5.9. A uniform application of 1 ton of calcic limestone per acre was made to the soil in June 1957 resulting in pH 6.1. Minor elements were in ample supply throughout the trial. The spring and fall treatments and harvests in 1957 were regarded as pre-trial conditioners and were not included in the results. However residual nitrogen from the fall application was available for growth in spring 1958 and will be reflected in total nitrogen recovered.

A randomized block design with 4 replications was used for each nitrogen source. These were superimposed on each of the 3 bases. A summary of the treatments is given in Table 1.

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TABLE 1.—SOURCE OF NITROGEN AND DESCRIPTION OF BASE TREATMENTS EMPLOYED IN NITROGEN SOURCE EVALUATION TRIALS AT RANGE CATTLE STATION 1957-59.

Nitrogen Source	Percent Nitrogen	Form Applied	Amount and Type of Nitrogen per Source and Base Given in Percent
Ammonium Nitrate	33.5	Dry	16.75 nitrate N. 16.75 ammoniacal N.
Urea	46.0	Dry	46.0 urea
Uran[1]	32.0	Liquid[2]	16.50 urea N, 7.75 nitrate N; 7.75 ammoniacal nitrate.
Feran[1]	21.0	Liquid[2]	10.50 ammoniacal N; 10.50 nitrate N.
Nitrate of Soda	16.0	Dry	16.0 Nitrate N.
Ammonium sulfate	20.0	Dry	20.0 ammoniacal N.
Base Treatment[3]			
0-8-8	Derived from 20% superphosphate and 60% muriate of Potash.		
8-8-8	Commercial 8-8-8		
8-8-8 (N-Dure)[1]	Experimental material[4]		

[1]Trade name copyrighted and material furnished by Nitrogen Division of Allied Chemical and Dye Corporation.

[2]Non-pressurized.

[3]Bases material applied in amounts sufficient to give 50 pounds of P_2O_5 and K_2O per acre basis in spring. No fall base treatments.

[4]Water Soluble N	2.12%	K_2O	8.40%
Nitrate N	1.15%	P_2O_5	8.46%
Ammoniacal N	1.79%	Citrate Soluble	
Urea N	1.24%	P_2O_5	0.41%
Moderately available N	1.96%		
Total N	8.26		

The experimental area was mowed, herbage removed, and a complete soil sample of 5 to 8 cores was taken for each plot in May 1957. The 3 bases of 0-8-8, commercial 8-8-8 and N-Dure were applied at this time with sufficient amounts of 8-8-8 and N-Dure to supply 50 pounds each of N, P_2O_5 and K_2O. Nitrogen sources were distributed on the 0-8-8 in both spring and fall. The other 2 bases received nitrogen in spring from the base treatment and from the nitrogen sources in the fall. Check plots for 0-8-8 base received no nitrogen from base treatment. Nitrogen from appropriate source was applied at the rate of 50 pounds per acre. Thus the yearly application of major elements in pounds of N-P-K totalled 100-50-50, representing the 2-1-1 ratio which is commonly used in pastures in peninsular Florida. The dates of fertilization and origin of nitrogen applied to plots is given in Table 2.

Plots were 10 x 10 feet in size. Base treatments were not replicated but were adjacent and initially were of comparable fertility and drainage. Herbage was cut with a cutter-bar mower and removed from the plots after green weights were taken and forage samples collected for moisture determinations. These samples were air-dried by forced air at 140° to 150° and yields expressed as tons of air-dry material per acre. They were then ground and composites from each nitrogen source and base treatment were analyzed for feed composition.[3]

[3]Analysis by Department of Animal Husbandry and Nutrition, University of Florida.

TABLE 2.—DATES OF FERTILIZATION AND SOURCE OF NITROGEN APPLIED TO PANGOLAGRASS.

Date	0-8-8	8-8-8	N-Dure
6-2-57[1]	Source	Base	Base
11-5-57[1]	Source	Source	Source
6-4-58	Source	Base	Base
8-20-58	Source	Source	Source
6-3-59	Source	Base	Base
10-6-59	Source	Source	Source

[1]Preliminary trial.

RESULTS AND DISCUSSION

The total yield in tons of oven-dry forage per acre for 1958 and 1959 is shown in Table 3. Pounds of nitrogen harvested in herbage and average percent crude protein for nitrogen source and base treatment are also given.

The data given in the preceding table can best be discussed considering (1) the 0-8-8 base as a separate trial to determine the effect of N from several sources on production of Pangola and (2) compare 8-8-8 base (commercial mixture) with N-Dure 8-8-8 (laboratory mixture) and 0-8-8 (mixture of 20 percent superphosphate and 60 percent muriate of potash).

The 0-8-8 base yields in tons of air-dry forage per acre ranged from 10.56 for urea to 11.22 for ammonium sulphate for the 2 years. The average of all sources was 11.03 tons per acre. Analysis of variance showed no significant differences in yield between nitrogen sources, but was highly significant between sources and check. The results of effect of nitrogen are

TABLE 3.—TONS OF AIR-DRY FORAGE AND POUNDS OF NITROGEN RECOVERED PER ACRE WITH AVERAGE PERCENT CRUDE PROTEIN FOR NITROGEN SOURCES AND BASES FOR 2 YEARS 1958 AND 1959.

Base	Check	Uran	Urea	Feran	NH_4NO_3	$NaNO_3$	$(NH_4)_2SO_4$	Average[1]
				Tons Air-Dry Forage				
0-8-8	6.29	10.61	10.56	10.02	11.13	11.22	11.72	11.03
8-8-8	10.21	12.96	12.49	13.02	13.27	12.46	13.09	12.88
N-Dure	8.55	11.66	12.29	13.13	11.23	11.33	12.17	11.97
	25.05	35.23	35.34	37.07	35.63	35.01	36.98	35.88
				Average Percent Crude Protein				
0-8-8	5.65	5.89	5.86	6.13	6.61	7.66	6.49	6.44
8-8-8	6.48	7.10	6.65	7.48	7.65	7.55	7.46	7.32
N-Dure	5.70	6.41	6.53	7.08	5.96	7.29	6.51	6.63
				Total Pounds Nitrogen in Forage				
0-8-8	94.8	156.9	151.6	168.9	175.9	201.5	195.9	175.2
8-8-8	174.3	233.3	213.2	240.8	238.6	243.3	244.7	235.7
N-Dure	132.8	200.6	213.5	252.2	169.9	222.4	205.3	210.7
	401.9	590.8	578.3	661.9	584.4	667.2	645.9	621.6

[1]Sources only.

in agreement with Volk (5) that there is little doubt that the increased knowledge of processes of nitrogen transformation in the soil is of utmost importance, and that at the same time it is reducing the concern for the original form of nitrogen applied as fertilizer. Wallace *et al* (6) concluded that under the conditions in which the experiment at Gainesville was conducted there would be no differences in response of Pangola or Pensacola bahiagrass to nitrate of soda and ammonium sulphate and Robertson *et al* (4) found that no one source of nitrogen was consistently superior or inferior to the remaining sources tested on general farm crops on Red Bay fine sandy loam.

The greatest variability in this trial was between the 3 bases. The average yield was 11.03, 12.88 and 11.97 tons of air-dry forage per acre for 0-8-8, commercial 8-8-8 and N-Dure 8-8-8 respectively. When plotted on graph paper the high and low points for 0-8-8 and commercial 8-8-8 are similar, although there is 1.85 tons difference in average production. There is no attempted explanation for the greater variability of nitrogen sources on the N-Dure 8-8-8 base. The ranking of total yield for the 3 bases by nitrogen source was Feran, ammonium sulphate, ammonium nitrate, urea, Uran and nitrate of soda. It is interesting to note that nitrate of soda, ranked sixth in total yield for the 3 bases, was first in average percent crude protein and pounds of nitrogen in the forage.

SUMMARY

Yields in tons of air-dry Pangola grass per acre produced by various sources of nitrogen were not significantly different for the 0-8-8 base under the conditions of this trial at Range Cattle Station for the 2 years, 1958-59. Greatest variability was between base treatments. An inverse relationship occurred in tons of air-dry forage per acre and percent crude protein and total pounds of nitrogen harvested.

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Yields and Quality of Pangolagrass Resulting from Different Fall Dates of Fertilization with Ammonium Nitrate and Muriate of Potash

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INTRODUCTION

Cattlemen and dairymen are interested in knowing the amount of production that may be expected from fertilization of grasses in the fall months, in order that they may determine, under conditions of pasture stress, if additional forage can be economically obtained from fall fertilization. To determine the effects of different dates of fall fertilization on the growth and quality of pangolagrass, four separate experiments were conducted on Immokalee fine sand.

EXPERIMENTAL PROCEDURES

One experiment was completed in 1956, two in 1957, and one in 1960. Plot sizes ranged from 10 by 10, to 12½ by 20 feet, and either a randomized block or split-plot design was used.

Nitrogen, phosphorus, and potassium were supplied in all instances as ammonium nitrate, 20% superphosphate, and muriate of potash, respectively. In some of the tests phosphorus was omitted because soil tests and the previous fertilization history indicated that sufficient phosphorus was present in the soil. In other tests phosphorus was applied uniformly at a rate of 60 pounds of P_2O_5 per acre. Sixty pounds of nitrogen per acre were used in three trials, and 75 pounds per acre were used in the remaining (1957) experiment. In three of the four experiments the effect of additions of potash was determined by applying 60 pounds of potash per acre to one half of all of the plots fertilized with nitrogen and leaving the other half without potash fertilizer. In the fourth instance the 60 pounds of potash per acre was applied to all plots.

In the 1956 experiment, plots were fertilized in August, September, October, November and December. The whole area was mowed originally on July 19, 1956. Plots fertilized in September and succeeding months were harvested just before fertilization. The August fertilized plots were harvested one month after fertilization. All plots were harvested again on January 7.

In the other three tests all plots were mowed just prior to the beginning of the test and then harvested at the end of the test.

Plots were harvested with a conventional 30-inch sickle-bar mower. A clipping height of about 2½ inches was used.

Representative samples of grass were dried at 70 to 75° in a forced-draft oven. Yields, dry matter contents and protein contents were obtained from

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these samples. The AOAC Method (1) was used to determine nitrogen in the grasses, and the crude protein values were obtained by multiplying the nitrogen contents by 6.25. Statistical techniques outlined by Patterson were used (2).

"Nitrogen utilization" as used in the text means the amount of protein (or nitrogen) in that portion of the grass that was harvested. The "percent nitrogen utilization" was calculated by dividing the pounds of nitrogen removed by harvesting by the amount of nitrogen applied and multiplying by 100.

RESULTS

Yields, Dry Matter and Protein—Dry weight yields are presented in Table 1. In order that the interpretation of results will not be misleading special note should be made of the 1956 data. Data not included in parentheses represent that obtained prior to fertilization except for the August fertilization data, where grass was harvested one month after fertilization on September 4. Data parenthesized refers to that obtained between the dates of fertilization and the January 7 harvest, except for the August fertilized plots which had already been harvested once, on September 4, after fertilization. A truer comparison between 1956 and the other years may be obtained by adding the yield data within and without the parenthesis for 1956.

Yields were lower when fertilization was delayed. The production of fertilized pangolagrass was greatest through the month of September in some trials, and through the month of October in others. Yields were not always progressively reduced from the early to the later fertilization dates, because of the influence of rainfall. A typical example was in the year 1960 when a reduction of about 1000 pounds dry matter occurred between the August 29 and September 19 dates. There was a total of about 12 inches of precipitation during this period, and more than 9 inches between September 22 and 26. Yields of the October 11 fertilized plots returned to about 5000 pounds. Pangolagrass fertilized with 60 to 75 pounds of nitrogen per acre after August 1 and before November 1 produced 3000 to 5500 pounds of dry matter per acre.

Dry matter contents decreased when yields decreased. Pangolagrass fertilized in August or early September and harvested in December or January contained about 40% dry matter. When fertilized approximately a month to six weeks before harvest, dry matter contents were as low as 18.9%. These data are presented in Table 1.

Crude protein contents, shown in Table 1, were higher when dry matter and yields were lower. Grass fertilized in August and early September with 60 to 75 pounds of nitrogen contain 2 to 3% crude protein. These protein levels increased to 11 to 13% when fertilization was delayed until November, which was a month to six weeks before harvest.

When grass was not cut just prior to fertilization at each date, the nitrogen utilization increased as fertilization was progressively delayed. This phenomenon may be noted in Table 1 for the experiments in 1957 and 1960. In 1960 the difference in protein between plots fertilized in August and September as compared with those fertilized in November was very large. Grass fertilized in August and September contained 140 pounds, while that fertilized in November contained 250 to 300 pounds of protein per acre.

TABLE 1.—THE EFFECTS OF DIFFERENT FALL FERTILIZATION DATES ON DRY WEIGHT YIELDS, DRY MATTER AND PROTEIN CONTENTS, POUNDS OF PROTEIN REMOVED AND UTILIZATION OF THE NITROGEN APPLIED TO PANGOLAGRASS

Fertilization Date	Yields lbs./A	Harvested prior to (1-7-57) fertilization	Dry Matter %		Crude Protein %		Crude Protein Removed lbs./A		Total Nitrogen Removed % of N applied
1956—60 lbs. N/A									
1. August 1	3070	(630)[1]	17.7	(40.3)[1]	8.7	(3.7)[1]	268	(23)[1]	77.6
2. September 5	600	(1480)	28.3	(39.9)	5.9	(2.9)	35	(43)	20.8
3. October 3	870	(1310)	33.1	(33.3)	3.3	(4.3)	28	(55)	22.1
4. November 2	1360	(630)	39.8	(25.2)	2.7	(7.2)	37	(44)	21.6
5. December 3	1010	(410)	40.5	(18.9)	2.7	(13.2)	27	(53)	21.3
L.S.D. .05		(530)		(1.6)		(0.8)		(11)	
1957—60 lbs. N/A	Harvested 11-4-57								
1. Check[2]	2650		41.1		2.2		57		---
2. August 5	5630		40.7		2.1		116		30.9
3. September 4	4230		38.3		2.4		101		26.9
4. October 4	3830		30.6		4.6		174		46.4
L.S.D. .05	910		1.8		0.5		34		
1957—75 lbs. N/A	Harvested 12-17-57								
1. August 20	4990		39.8		2.7		134		28.6
2. September 3	5120		40.6		2.9		148		31.6
3. September 17	3810		40.9		3.4		129		27.6
4. October 1	2820		37.1		3.9		109		23.3
5. October 15	4150		31.7		6.9		288		61.5
6. October 29	3390		34.5		7.4		247		52.8
7. November 12	2270		31.0		11.0		256		54.7
L.S.D. .05	760		4.8		0.6		65		----

TABLE 1.—CONTINUED

Fertilization Date	Yields		Dry Matter	Crude Protein	Crude Protein Removed	Total Nitrogen Removed
1956—60 lbs N/A	lbs./A Harvested prior to (1-7-57) fertilization		%	%	lbs./A	% of N applied
1960—60 lbs. N/A		Harvested 1-16-61				
1. August 29	5050		46.6	2.8	140	37.3
2. September 19	4020		43.7	3.4	137	36.5
3. October 11	5010		36.4	4.2	210	56.0
4. November 1	3930		29.8	6.3	247	65.9
5. November 23	2650		24.0	11.3	297	79.2
L.S.D. .05	430		1.9	1.2	25	

[1]All plots were clipped on July 19 and all plots were clipped again prior to fertilization except those of Aug. 1 which were harvested on Sept. 4. Values not in parenthesis represent harvests prior to fertilization (except Aug.) while those data in parenthesis were obtained after fertilization (except the Aug. plots).

[2]Yields during entire period without fertilization.

When plots were mowed and clippings removed just prior to each date of fertilization a different phenomenon occurred. This can be seen by noting the data for the 1956 experiment in Table 1. Except for the August fertilization there was little difference between fertilization dates in effect on nitrogen utilization by the pangolagrass. However, fertilizing in August and harvesting one month later resulted in the largest percent nitrogen utilization.

Percent nitrogen utilization is recorded in Table 1 and varied from 20.8 to 79.2%. Generally, 50% or more of the nitrogen was utilized only when the grass was fertilized later than the first of October. A pre-treatment application of 45 pounds of nitrogen per acre about three weeks prior to the initiation of one of the experiments in 1957 resulted in an average increase from a utilization of 43% compared to 37% for the non pre-treated grass. The reason for this relatively small increase evidently was associated with the increased yields resulting from pre-treatment fertilization and consequently diluted protein in the tops.

Response to Potash Fertilization—In Table 2 the results of three years experiments are given dealing with the response of pangolagrass to applications of potash when soil potash levels were initially low. A yield increase occurred only for the 1960 experiment, and the dry matter and crude protein contents were significantly lowered when potash was applied. In the 1956 experiment, even though there was no yield response, grass receiving potash contained less protein.

DISCUSSION

There is a distinct problem in fertilizing pangolagrass or other grass in the fall if one application of fertilizer is used. It is difficult, because of rainfall and temperature differences every year, to pick the date of fertilization where maximum economic yields and satisfactory protein contents

TABLE 2.—THE EFFECTS OF POTASH FERTILIZATION ON PANGOLAGRASS DRY WEIGHT YIELDS, DRY MATTER AND PROTEIN CONTENTS, CRUDE PROTEIN REMOVED AND UTILIZATION OF THE NITROGEN APPLIED

	Year	Soil K Contents Prior to Fertilization lbs./A	Potash Fertilization Rate lbs./A	Yields lbs./A	Dry Matter %	Crude Protein %	Crude Protein[1] Removed lbs./A	Nitrogen[1] Removed *% of N applied*
1.	1956	24	a. 0	1530	31.6	6.5[2]	92	25
			b. 60	1470	31.5	6.0	85	23
2.	1957	30	a. 0	3730	38.1	2.9	108	29
			b. 60	3860	38.6	2.7	109	29
3.	1960	27	a. 0	3180	39.5[3]	6.8[3]	196	52
			b. 60	4130[3]	36.1	5.6	206	55

[1]Not analyzed statistically.
[2]Statistically significant at the 5% level.
[3]Statistically significant at the 1% level.

may be obtained for a particular harvest or grazing date. Furthermore, the time when the grass is needed most also depends upon climatic conditions. Certain years a heavy frost early in the fall might make it necessary to utilize the reserve pasture earlier than in other years when frosts occur later or do not occur at all. According to our results, a cattleman interested in obtaining maximum grass growth without regard for quality, should fertilizer early in September and no later than the first of October. A rancher who is interested in obtaining a good quality grass and will accept less tonnage should fertilize about the middle of October and not later than the first of November. Areas north and west of the Indian River Field Laboratory normally have more severe winters and these dates of fertilization should be changed accordingly. Probably fertilizing about two weeks earlier than the above suggested dates would result in satisfactory yields and protein levels.

A generally approved fertilization program for most grasses is to alternate a complete 1-1-1 ratio fertilizer with the application of straight nitrogen. Ranchers who normally fertilize their grass pastures and particularly pangolagrass pastures twice a year, (once in the fall and once in the spring), should probably apply the potash in the spring because there is less chance of leaching during this time of year.

There may be certain advantages to fertilizing twice in the fall. Enough nitrogen could be used in the early fall to assure good grass growth and then another application could be applied a few weeks prior to grazing or cutting for hay or other purposes, to increase the protein levels and palatibility.

The reason that better utilization of nitrogen was obtained from grass fertilized late in the fall compared to grass fertilized early in the fall is not known. This better utilization may have been due to reduced leaching of the nitrogen, or possibly because better utilization is obtained when grass has a relatively large proportion of leaves and or roots at the time of fertilization. Results indicated that better nitrogen absorption and retention occurred when the grass was allowed to grow without fertilization until it had produced several to many leaves. Fertilization after this had occurred resulted in more efficient movement of nitrogen into the grass tops than when nitrogen was applied immediately after clipping.

In a review of the effect of defoliation on root growth Throughton (3) stated that the main effect was to retard growth for a period of time depending upon the severity of defoliation and other factors. Also, the number of roots initiated and the root volume is reduced. Root growth was found to be reduced more than shoot growth, the difference between the growth of the root and shoot decreasing as the plant recovers from the defoliation. Defoliation not only decreases the life of roots but roots of defoliated plants have been shown to die back from the tips. In most experiments, height of cutting had a greater influence on the severity of root damage than frequency of cutting.

Throughton (3) also discusses nitrogen nutrition. In general he states, "It appears that plants grown in conditions where available nitrogen was a factor limiting growth have a well developed root system, but a poorly developed shoot system. Plants grown with an excess of nitrogen exhibit the opposite relative development."

From the above facts, pangolagrass in the 1956 test where the grass was cut twice (the second time immediately prior to fertilization) would have been expected to have a weaker root system than that of the other tests

where it was mowed once and then fertilized some time later after roots and shoots had regrown more fully. If this phenomenon proves to be true it would have considerable practical significance because of the much better utilization of the nitrogen obtained when the grass was allowed to regrow prior to fertilization.

Except for the 1960 experiment, the yield responses to potassium applications in the fall were not large, even though the soil levels of this element were very low (Table 2.). The effect of these low soil levels, however, was pronounced on the late spring yields obtained in certain of the tests where the grass was refertilized with nitrogen (and without potash) in the spring. Grass growth in the fall (when responses to potash were slight or non-existant) presumably was limited more by cold weather than by lack of potash. In the spring, when the growth was more rapid potash deficiency severely limited production. In both fall and spring when yields were limited by a lack of potash, the protein contents were higher than where potash had been applied.

Under conditions of grazing, the fall fertilization date should be about the same as those suggested earlier for either production of tonnage or production of quality of feed. Under conditions of grazing rotationally or almost continuously throughout the winter it might be best to initiate grazing in the middle of November to the middle of December. When planning to make hay or green-chop the harvest date might be slightly later than these grazing dates. Aphids or frost can upset plans for delayed grazing, therefore, provision should be made for those years when it might be impossible to reserve the pasture until the need for food reaches its peak.

SUMMARY

1. Maximum yields were obtained when pangolagrass was fertilized before October 1. Protein contents were about 2.5 to 4.0%.
2. Grass fertilized between October 15 and November 15 generally yielded less but contained more protein than that fertilized earlier.
3. The quantity of protein (or nitrogen) found in the tops of the pangolagrass became greater as fertilization was progressively delayed in the fall.
4. The percent nitrogen utilization varied from about 20 to 80% and depended upon the year and date of fertilization.

ACKNOWLEDGEMENTS

Acknowledgement is due Mr. L. E. Hostetler, Field Assistant without whose help, the work reported could not have been completed, and to Dr. C. T. Ozaki, former Assistant Soils Chemist, Everglades Experiment Station, for supervision of some of the protein analyses and for his valuable suggestions.

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Fertility Responses of St. Augustine, Pangola, and Pensacola Bahia Grasses on South Florida Sandy Soils[1]

FREDERICK T. BOYD[2]

In recent years the trend has been toward the use of three tropical grasses to establish permanent pastures in South Florida. Pensacola bahiagrass (*Paspalum notatum*), pangolagrass (*Digitaria decumbens*), and St. Augustinegrass (*Stenotaphrum secundatum*) have been found adapted to local climatic and soil conditions and have met the livestock and production requirements of the area. Pensacola bahiagrass and pangolagrass are better able to withstand drought conditions than St. Augustinegrass and, therefore, are more likely to be planted on the drier sandier soils. Pangolagrass is the most frost-sensitive of these 3 grasses, but makes a lush growth during the midsummer months. Because of the aggressive summer growth, large acreages of pangolagrass are cut for hay and silage. All of these grasses are highly responsive to heavy fertilization, especially where soil moisture conditions are adequate.

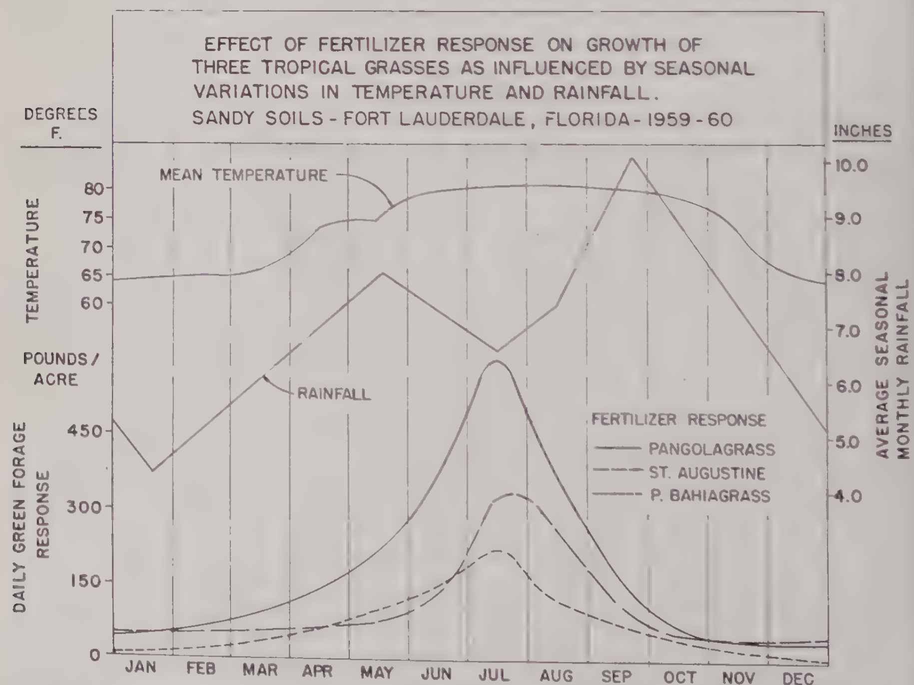

Fig. 1.—Influence of rainfall and mean monthly temperatures ranging from 64° F. to 80° F. on immediate fertilizer response of three pasture grasses.

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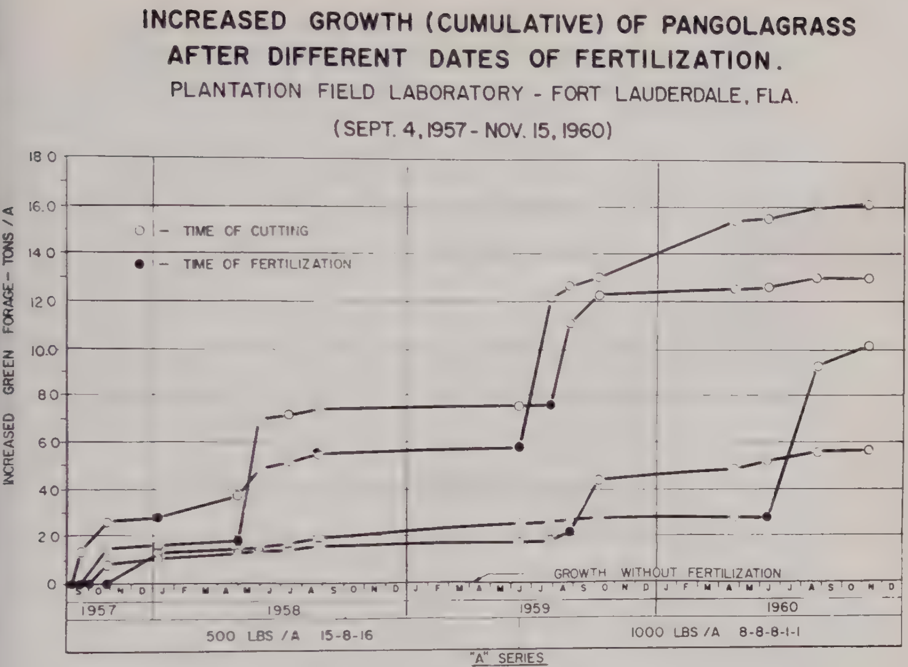

Fig. 2.—Growth response of pangolagrass from low nitrogen fertilization.

Responses of these grasses to high levels of applied N, have been reported by various Florida workers. Blue and Gammon (1) obtained increased pangolagrass yield with 288 pounds of added N. Engibous *et al.* (3) found that a maximum of 240 pounds of N per year was justified in yields from Pensacola bahiagrass. Pangolagrass responded with N application rates up to 320 pounds per acre per year.

Wallace *et al.* (4) obtained favorable responses by bahiagrass and pangolagrass to N applications up to 240 pounds per acre per year. St. Augustinegrass (2) responded to N treatments up to 180 pounds per acre per year with 54 pounds P and 150 pounds K.

EXPERIMENTAL PROCEDURES

Experimental plots were staked out August 13, 1957, in areas of Pensacola bahiagrass, pangolagrass, and St. Augustinegrass. Bahia and pangolagrass trials were on Arzell sand, while St. Augustinegrass was grown on Davie fine sand. Fourteen treatments in each grass area were arranged in quadruplicate randomized blocks. Half of the plots in each area were labeled "B" plots or "high-nitrogen" plots, and were fertilized August 14, 1957, with 50 pounds of N in the form of NH_4NO_3. The remaining plots were designated as the "A" series or "low-nitrogen" plots. All plots were cut September 3, 1957, and plots 1A and 1B were fertilized with 75 pounds N, 18 pounds P, and 67 pounds K per acre. Successive dates of application on plots 2, 3, 4, 5, and 6 were September 18, October 2, 16, 30, and November 15, 1957, respectively. Plots 7A and 7B received no additional fertilization and 7A plots served as controls after August 14, 1957.

Retreatment of plots 1 and 2 began January 17 and May 8, 1958, re-

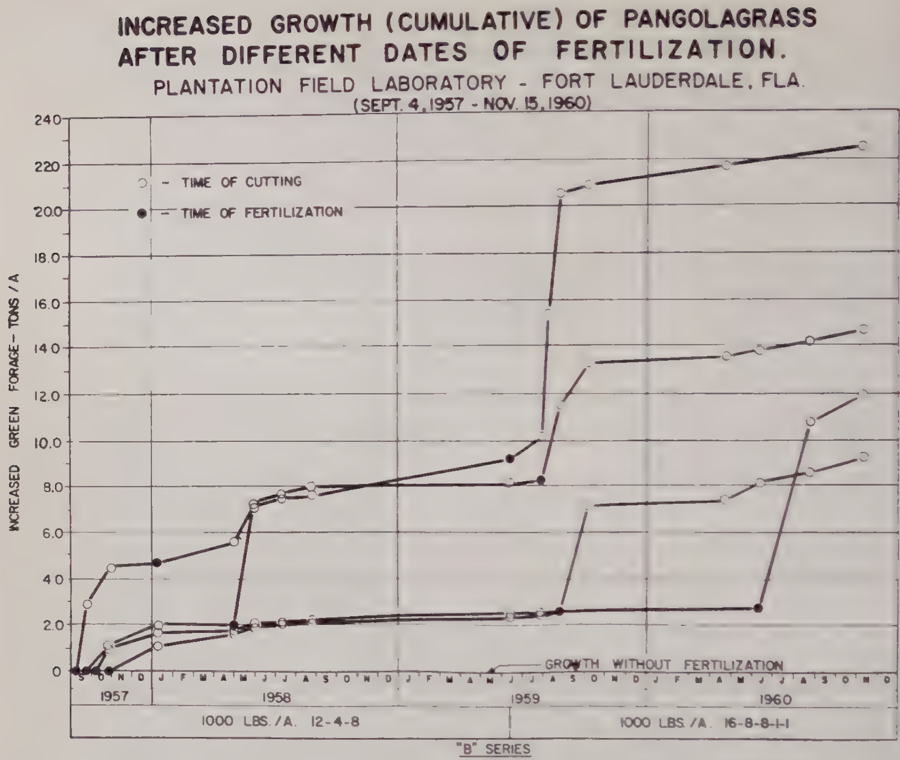

Fig. 3.—Growth response of pangolagrass from high nitrogen fertilization.

spectively, but was discontinued until June 30, 1959, when 500-pound applications of 8-8-8 ("A" plots) and 16-8-8 ("B" plots) were substituted for the above formulae. One unit of CuO and MnO was included with each fertilization treatment. Successive fertilizer applications have been made June 30, July 30, August 26, and October 19, 1959; and May 2, and June 23, 1960.

Plots 1 and 2 were fertilized 4 times after the trials began. Plots 3, 4, and 5 were fertilized 3 times, and plots 6A and 6B were fertilized but twice. Plot 7A received no fertilizer, and plot 7B received only 50 pounds N August 14, 1957.

Soils from untreated plots were sampled November 1, 1957, and were analyzed for pH and water soluble P and 0.5 N HOAc bases by the soils laboratory at the Everglades Experiment Station, Belle Glade, Florida. Soil pH varied from 5.2 to 6.1 on the different areas. All soils were characterized by low available phosphorus and base nutrients.

CLIMATE

Rainfall records for the period of these experiments have shown that the 6 summer months generally have about twice as much precipitation as the winter period. Months of over 8 inches of rainfall produced less growth of forage due to severe leaching of soluble plant nutrients. Months with mean temperatures below 70° F. did not give satisfactory growth of the grasses tested.

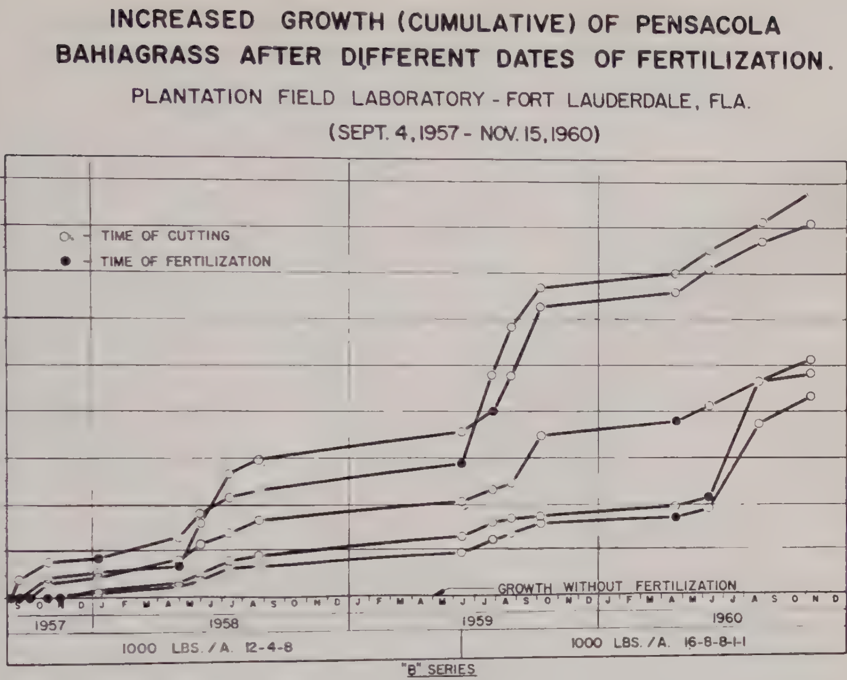

Fig. 4.—Growth response of Pensacola bahiagrass from low nitrogen fertilization.

RESULTS AND DISCUSSION

*Effect of Time of Fertilization on Forage Yield Response**

Figure 1 shows that, except in degree, St. Augustine, pangola, and Pensacola bahia grasses are similarly affected by weather conditions. Fertilizer applied during the late fall and winter months had little immediate effect on the growth of any of these grasses. All grasses responded quickly to fertilizer applied from April through September. Temperatures were sufficiently high for good growth in October, but rainfall seemed to be the limiting growth factor during the fall months. Successful fertilizer application is possible in October if followed by good rains, or if applied to grasslands having adequate surface soil moisture.

While pangolagrass gave the greatest growth response to mid-summer fertilizer application, St. Augustinegrass gave the highest *total* yearly production of forage and produced the most growth during the winter months. Pensacola bahiagrass gave the least growth increase after fertilization.

Comparison of Fertility Responses of Different Fertilizers on Forage Grasses.

Fertility response of St. Augustine, pangola, and Pensacola bahiagrass is shown graphically in figures 2, 3, 4, 5, 6, and 7. These graphs give the cumulative differences in yield between fertilized plots and the control, or the amount of forage production attributable to fertilizer added. The suc-

*In this paper, "fertility response," "growth response," "increased growth," and "forage yield response" are defined as the amount of forage harvested in excess of that produced on corresponding control or check plots.

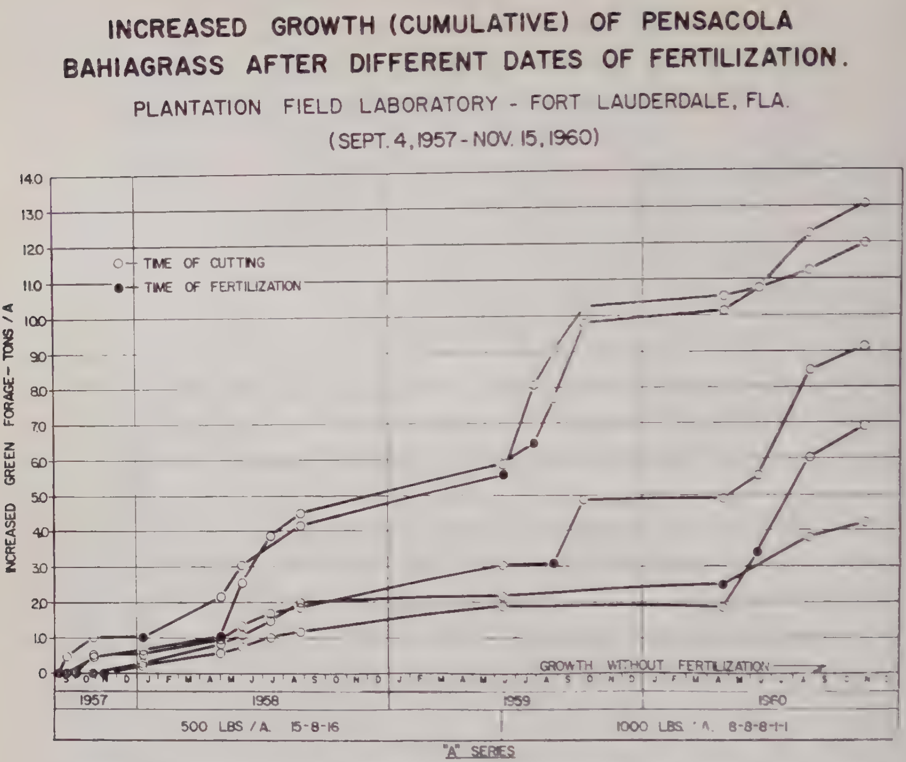

Figure 5.—Growth response of Pensacola bahiagrass from high nitrogen fertilization.

cessive yields from check plots or "growth without fertilization" are represented in the figures by the base line from which the fertilizer response curves progressively digress with each harvest. Figures 2 and 3 show this increase of pangolagrass from complete fertilizer with low nitrogen ("A" series), and high nitrogen ("B" series). Figures 4 and 5 show respectively the response of Pensacola bahiagrass from low-N fertilizer (series "A") and high-N fertilizer (series "B"). Lastly, figures 6 and 7 show the fertilizer responses of St. Augustinegrass in the same manner.

In figures 2 and 3 for pangolagrass, and figures 6 and 7 for St. Augustinegrass, 2 treatments are omitted. Figures 4 and 5 show the results from all but one of the treatments. Intermediate treatments were omitted to avoid loss in clarity of the data presented on these graphs.

Each grass gave immediate responses after summer fertilization while only negligible responses followed late fall or winter fertilization. Fertilization was always accomplished directly after the plots were harvested.

Pensacola bahiagrass and pangolagrass on Arzell sand gave a greater proportionate response to higher N fertilization than St. Augustinegrass on Davie fine sand. Bahiagrass which received 4 applications of 1,000 pounds per acre of 16-8-8 yielded 38% more forage than similar plots treated with 8-8-8. Pangolagrass with 16-8-8 produced 36% greater tonnage than that treated with 8-8-8. St. Augustinegrass on Davie fine sand produced only 14% more grass with 16-8-8 than with 8-8-8. All fertilizers contained 1 unit each of CuO and MnO. The time of fertilization, kind of grass, and

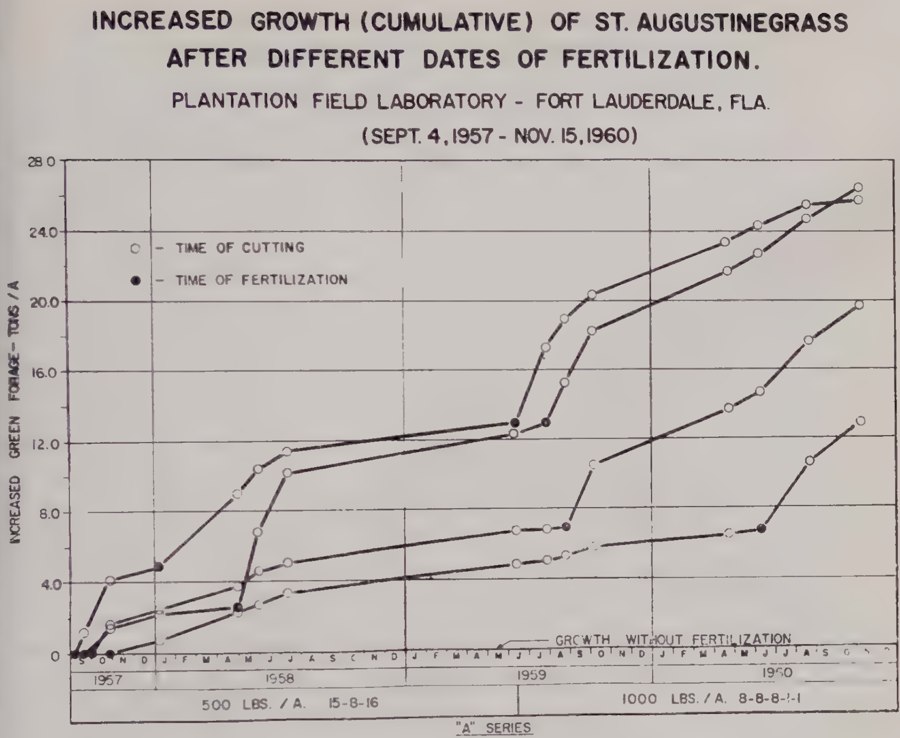

Fig. 6.—Growth response of St. Augustinegrass from low nitrogen fertilization.

grade of fertilizer all contributed to the forage response from fertilization.

SUMMARY

St. Augustinegrass, pangolagrass, and Pensacola bahiagrass were grown on sandy soils near Ft. Lauderdale, Florida, and treated with 2 grades of fertilizer at various times over a three-year period. St. Augustinegrass on Davie fine sand produced the highest total forage yields and the most growth during the winter months. Pangolagrass on Arzell fine sand gave greatest immediate mid-summer fertilizer response and the highest proportional increase from higher N fertilization. Bahiagrass produced lowest total forage yields. Fertilizer response of all grasses was similarly affected by climatic conditions, being adversely affected by drought and low winter temperatures and by seasons of high rainfall intensity.

Positive fertilizer responses were greatest in midsummer and lowest from the middle of October to early April. Fall fertilization was effective on sandy soils when followed by moderate rains or when applied to grasslands having adequate surface soil moisture.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to John Howerton and Virginia Larrick for preparation and photography of graphs.

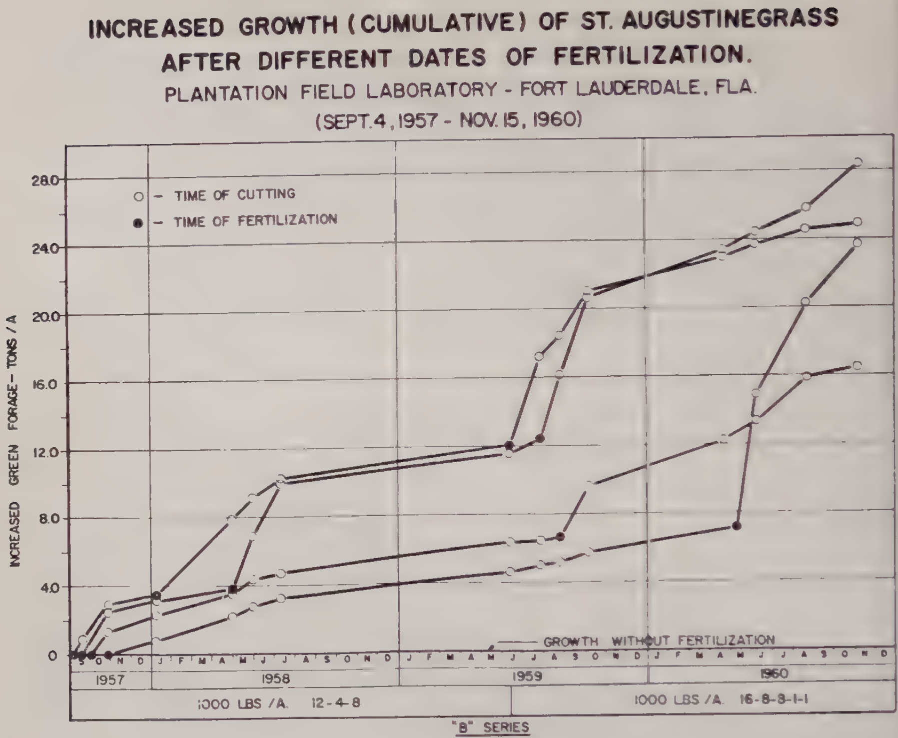

Fig. 7.—Growth response of St. Augustinegrass from high nitrogen fertilization.

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CONTRIBUTED PAPERS (CROPS)

Gordon M. Prine, *Presiding*

Evapotranspiration Studies in Florida[1]

ABSTRACT

JOHN C. STEPHENS[2]

First, this paper describes studies in central and southern Florida to evaluate the Weather Bureau evaporation pan as an indicator of normal evaporative processes under subtropical conditions. The relations found between evaporation from the standard pan and lakes, soil, grass, and truck crops are cited.

Next, the validity of eight semiempirical formulas used to compute monthly evaporation from climatic data was tested by graphical comparison with pan records. A new, simple and relatively accurate formula was developed. Regression equations and coefficients of determination have been used to rank the formulas in order of accuracy.

Finally, a method of determining monthly consumptive water use for Florida watersheds which requires only USWB pan and rainfall records is explained. This method is afterwards checked by the water budget procedure and found capable of predicting annual runoff from experimental watersheds within close limits.

[1]Due to length of this paper and the substantial part of it devoted to meteorological methodology it was thought best to limit its publication in this Proceedings to the abstract especially since the entire treatise is to be published by the U. S. Department of Agriculture in its ARS 41 Series.—Ed.

[2]Hydraulic Engineer, Soil and Water Conservation Research Division, USDA and University of Florida, Plantation Field Laboratory, Ft. Lauderdale, Fla.

History of Sugar Cane Production and Areas Suitable for Expanding its Culture in South Florida

B. A. BOURNE[1]

The history of sugar cane cultivation in Florida shows that this crop was used for sugar manufacture on a commercial scale as early as the period from 1767 to 1776 at the New Smyrna Colony. After this Colony was disbanded in 1777 the sugar industry was lost to the State. However, during the early Colonial period there can be no doubt that sugar was manufactured by crude methods, since ruins of old cane mills and syrup vats furnish evidence of such ventures in various places in Florida such as Port Orange, DeLeon Springs and in the neighborhood of the old New Smyrna Colony.

Between 1850 and 1860, Major Robert Gamble of Tallahassee moved to Manatee County and erected a sugar mill to process the cane grown in the vicinity of the plant. By 1860 the U.S. census showed an annual output of 2,002,800 pounds of sugar from this mill, but the venture was later ruined by the Civil War and a disastrous fire.

The next large cane sugar producing operation was developed at St. Cloud in the Kissimmee River Valley by Captain R. E. Rose, then State Chemist, who took Hamilton Disston into partnership with him. Hamilton Disston was President of The Disston Land Company, an affiliate of the Atlantic and Gulf Coast Canal and Okeechobee Land Company, which was originally chartered by special act of the Florida Legislature in 1881. Incidentally, in an undated bulletin published for the above land company by the Times Printing House, Philadelphia, Pa., some of the first analyses of Everglades peat have been noted and a comparison made between the composition of these soils and those of Jamaica and Demerara as cane growing media. The booklet also refers to an article in the Louisiana Planter and Manufacturer for April, 1890, citing in detail the operation of the Sugar Mill at St. Cloud for the season of 1889-1890. From 357 acres, 8,578 tons of cane were milled with a yield of 8.4% sugar and a total production of 1,442,900 pounds. The average cane yield was 24 tons per acre. Figure 1 shows the harvesting and loading of sugar cane into mule-drawn carts at St. Cloud Plantation, Kissimmee, Florida while Figures 2 and 3 are outside and inside views of the St. Cloud factory in 1890.

The variety (or varieties) of sugar cane used commercially in the St. Cloud venture has not been determined, although reference was made once to "red ribbon cane." It is entirely possible that Otaheite, Louisiana Purple and its mutation Louisiana Striped or Red Ribbon were involved.

It is always of interest to study the cause of failure of an agricultural development for, by so doing, perhaps future mistakes and failures can be avoided. It has been the good fortune of the writer to have access to old records which will be of interest in this connection. In a newspaper clipping from Tallahassee, Florida, dated 1905, it was reported that the original St. Cloud sugar producing venture controlled by Captain R. E. Rose was a marked financial success and even with sugar selling at 3 to 4 cents per pound 40% dividends were possible. However, Hamilton Disston saw in

[1]Vice President in Charge of Research, United States Sugar Corporation, Clewiston, Florida.

Fig. 1.—Harvesting and loading of sugar cane with mule-drawn carts. St. Cloud Plantation.

this success an opportunity to form a large stock company. But when Captain Rose refused to join in this idea the two parted company and Mr. Disston organized a large company in March 1892, known as the Hamilton Disston Sugar and Rice Company, Inc., after buying out Captain Rose's interest in the original development. Over capitalization, large salaries and poor management combined to ruin the already successful smaller venture. In an extended article published by the Valley Gazette, Kissimmee, Florida, dated April 30, 1906, Captain Rose listed the failure as due to:—

1. Lack of agricultural skill and knowledge.
2. Extravagance in local management, neglect of fields and particularly neglect of local drainage.
3. Overcapitalization and the investment of capital in unproductive lands; the mortgaging of the property for more than its value and earning capacity.
4. Repeal of the U. S. Bounty Law and loss of stockholders' confidence.

Captain Rose also stated in this article that the report of operations at St. Cloud for 1889 and 1890 showed the remarkable yields of 4,000 pounds of sugar per acre from 357 acres. He also stated:

"After long experience in Louisiana and twenty-five years in Florida, where I have been familiar with sugar culture and manufacture, I do not hesitate to say, the reclaimed marsh lands of Florida will produce more and better sugar cane than any lands in the United States; that they will produce cane equal to Cuba, or Mexico in tonnage of saccharine quality."

"Cane from the reclaimed lands of Southport, near St. Cloud, received the first premium in competition with the world, at the New Orleans Exposition in 1885. Cane from St. Cloud showed the best average yield

Fig. 2.—External view of St. Cloud sugar factory in 1890.

of sugar of any American sugar estate for 1888, '89 and '90; the same quality of cane is still growing on these lands and was exhibited at Tampa last winter. No fertilizer of any kind was used at either place on cane."

"See Dr. H. W. Wiley's report on soils and products in the agricultural report of 1891. This report was made by Dr. Wiley after years of personal investigation at St. Cloud, Southport and Runnymede, where he was in charge of the sugar experiments of the U. S. Agricultural Department."

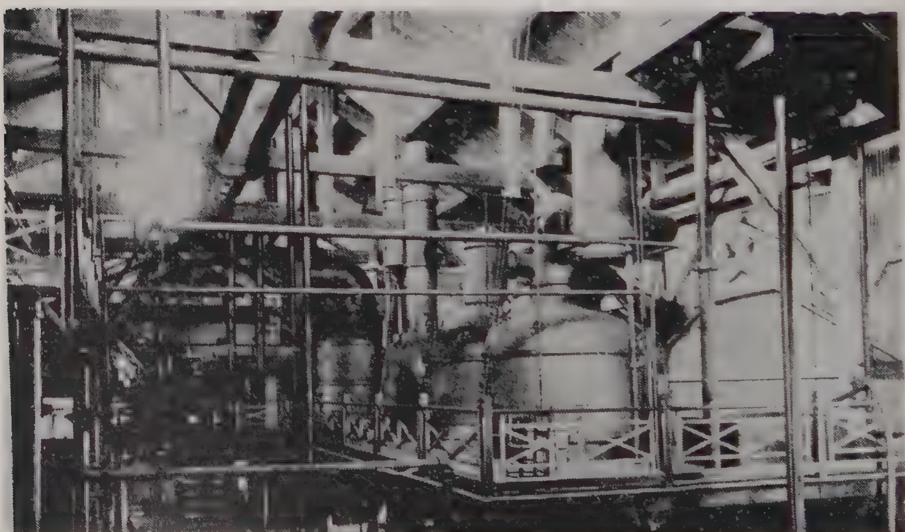

Fig. 3. Internal view of St. Cloud sugar factory in 1890.

Following the ceding of the Everglades to Florida by the Federal Government under the terms of the Swamp And Overflow Lands Act of 1850, by which the State was obliged to drain and develop the area, interest in crops suitable to the region had been continuous. Because of the previous commercial experience with sugar cane growing in the Kissimmee area at St. Cloud, Southport, Runnymede and other adjacent areas, it was only natural that this crop would be tried further to the south. Plantings were made during the early part of the 20th century up to 1920 in Moore Haven by the Moore Haven Sugar Company, and in the Disston Island and Canal Point districts. The Florida Sugar and Food Products Company at Canal Point may well be considered the starting point of the present large commercial sugar cane growing and processing operations in the Everglades. Before 1923 Mr. F. E. Bryant, G. T. Anderson and Associates transported by barge from West Palm Beach to Canal Point a second-hand 400 ton cane mill to handle several hundred acres of cane bordering Lake Okeechobee, mostly of varieties Crystalina and D.74.

By 1924 a small cane planting had been made at Hialeah where the Pennsylvania Sugar Company had erected a modern 2400 ton cane mill. Poor drainage, lack of adequate fertilization, especially with the trace element copper and the use of mosaic susceptible varieties caused this company to abandon the project.

By 1925 The Southern Sugar Company acquired large tracts of lands around the south and southwest rim of Lake Okeechobee and purchased and transported the Pennsylvania Sugar Company's mill at Hialeah to Clewiston, where it was erected and modernized to handle their expanding cane acreage. By the 1928-29 crop season, 1000 acres were harvested and yielded only 13 tons of cane per acre with a sugar content of only 7.70%. Since, by that time, the Southern Sugar Company had acquired the mill and other properties of the Florida Sugar and Food Products Company, all the cane from Canal Point and around the southern portion of the Lake was milled at the more modern Clewiston plant. The Southern Sugar Company expanded its acreage during 1929 and 1930 very rapidly using the only available varieties, viz: D.74, Crystalina, P.O.J.36, P.O.J.36-M, P.O.J.-2714 and a few other imported varieties. By the crop season of 1929-30 the company harvested 7,000 acres with an average cane yield of 28.9 tons per acre and sugar yield of only 6.95%. Lack of adequate knowledge concerning the adaptability of the various imported varieties to the existing soil types, the rapid spread of mosaic virus disease to all varieties except P.O.J.2714, ignorance in regard to adequate fertilization and soil amendments as well as proper land preparation and finally overexpansion in the face of one of the nation's worst financial depressions resulted in this company going into receivership on June 30, 1930. After operating in receivership for the crop of 1930-31 the United Sugar Corporation acquired all the properties of the Southern Sugar Company in April, 1931. Even though much field loss was experienced by rodents during the 1930-31 crop season, some 12,000 acres were harvested and yielded an average of 29.2 tons per acre of cane with 7.70% yield of sugar.

Credit for establishing in June, 1929 the first sugar cane research station devoted exclusively to the development of the Florida sugar industry in the Everglades must be given to the President of the Southern Sugar Company, Mr. B. G. Dahlberg. Agronomic studies, including cane breeding, soils and fertilizer requirements were begun by the company on the above date and had much influence in attracting new capital from the organizers

of United States Sugar Corporation who had faith in the research work in progress for two years before they acquired possession in 1931. In fact, had it not been for the extensive collection of important breeding canes brought together by the U. S. Department of Agriculture at Canal Point during the early years and their well planned use in a private research program that followed, which included the development of new and more adaptable disease-resistant varieties for local use simultaneously with the initiation of an intensive study of sugar cane cultivation and fertilization, along with the new capital supplied by forward-looking business men such as Mr. Charles Stewart Mott, whose interest was aroused by the soundness of this basic approach, it is almost certain that the present major segment of the Florida sugar industry, which has enjoyed successful and profitable operations for the past thirty years would have ceased to exist. Under such circumstances it is improbable, of course, that such other companies as the Fellsmere Sugar Producers Association or the Okeelanta Sugar Refinery, Inc., would ever have come into existence.

An additional comment might be made in favor of intensive research as a basis for successful commercial cane sugar production. This has to do with the history of the relatively new commercial development at Okeelanta. This cane growing enterprise was originally started during World War II. The mill, of 2,500 ton capacity, was originally erected on Vieques Island a short distance off the east coast of Puerto Rico. Because of the use of this island for war maneuvers and the urgency of increasing sugar supplies on mainland United States, the Puerto Rican owners decided to develop a sugar plantation and remove this mill to the muck lands about 9 miles south of South Bay, Florida. Navy transport was used to move the factory, and prisoners of war were used for the construction work and for the building of roads and dikes to and around the factory.

Because of the necessity of acquiring between 18,000 and 20,000 acres of land and the expenses incidental to installing ditches and drainage facilities, the finances of the developers were spread so thin that the Columbia Bank of Cooperatives of Columbia, South Carolina, a mortgage lending institution, was forced to take over this enterprise during 1948-1949.

Unfortunately, those officials who were originally responsible for the local management of the property made the sad mistake of planting the major portion of their plantation to frost susceptible, late maturing varieties. In addition to this, lack of experience in soil fertilization and cultural requirements peculiar to the local sub-tropical environment and the organic soils contributed to lower cane yields which in combination with a low sugar content resulted in financial failure. The property was sold to Okeelanta Sugar Refinery, Inc. in August, 1952.

The successor company, profiting by the mistakes of their predecessors, hired a locally trained and experienced field manager familiar with subtropical sugar production problems and the importance of using cold-resistant, early maturing cane varieties under South Florida conditions. The new company has made a marked financial success during the past eight years. During this period it has even expanded by acquiring, in 1958, the Fellemere Sugar Producers' Cooperative properties at Fellsmere, Florida, which has its own 1500 ton mill and 150 ton daily refined sugar capacity. This enterprise, originally owned and operated by Fellsmere Sugar Company, is located about midway between Jacksonville and Miami, 12 miles west of Sebastian. In the early 1930's it produced only raw sugar; but since 1935 it has refined and marketed sugar under the trade name of "Florida

Crystals." It has the distinction of being the first factory in the State to produce refined sugar from locally grown cane and still remains the only sugar refining enterprise in Florida. The sugar producing area of this mill is about 7500 acres, however, the soil and climate in that section of the State are so different that an entirely different group of cane varieties than those used in the Everglades has been selected for use in that area, viz: C.P.34-79, F.36-819 and C.P.50-28. The yield of cane for many years usually has been only about 18 tons per acre. Since this is low, intensive studies are presently in progress in an effort to bring about improvement.

In general review it is seen that there have been not less than 13 attempts to produce raw cane sugar commercially in Florida between 1767 and early 1960. Of these, only two companies have made outstanding financial successes and they are both companies which purchased former companies that had made financial failures out of their efforts. In both cases the only factors which brought success were the use of locally bred, well adapted, high yielding cane varieties and proper attention to providing adequate drainage and fertilization.

All of the prior experience also points to the fact that both cane diseases and poor adaptability of varieties were major contributors to failure. Most imported cane varieties either proved too late maturing for the short growing cycle of sub-tropical Florida or were unable to ripen with high percentage yields of sugar when grown on high nitrogen organic soils with relatively high moisture contents.

Mosaic disease, ratoon stunt, stem rot and red rot have all contributed to the major losses that have been experienced in commercial yields in the past. Because of the constant threat of mutation of existing strains of pathogenic viruses and fungi, only cane breeding and selection as a continuous program can be counted on to prevent ultimate failure in the future. There is also the threat of importing new cane diseases, in spite of quarantine measures now in existence. It is obvious that every effort should be made to strengthen existing quarantine laws.

Most of the allotted time has been spent reviewing the past history of commercial cane growing ventures in Florida and their failures and successes. We now come to a consideration of the areas suitable for sugar cane production in this State. In doing so, let us not forget past history and the clear facts they reveal. The answer to the "where" and the "how" of future sugar cane production possibilities in South Florida certainly should be based on existing facts and especially those which have become established by actual experimental trials. It is the opinion of the writer that successful and profitable sugar cane culture is possible in almost all areas in Florida southward from a line drawn east and west across the state to include the sections covered by the original St. Cloud development in the Kissimmee Valley provided the following essentials are fully taken into account:

1. The land should have a soil depth of at least 3 to 4 feet.
2. The rainfall should average between 50 to 75 inches annually and be well distributed.
3. The lands of all types should be provided with adequate drainage facilities capable of removing a minimum of 1" of water in 24 hours.
4. In sandy soils with less than 25% organic matter provision should be made to control the water table during extended periods of dry weather (irrigation).

5. The chemical composition of the various soils that are to be used for sugar cane should be carefully studied and exhaustive fertilizer experiments carried on in advance of planting for 4 or 5 years with those varieties known to be most adaptable to a particular area in order to determine the correct fertilization required for each type, including amendments with special trace elements.
6. Large numbers of the most promising cane varieties available should be compared in properly replicated experimental plots for at least three crop seasons to determine which are best adapted and capable of giving the highest yields of sugar per acre at minimum cost. This will involve sugar analyses of the canes from all plots made both early and late in the milling season and total cane weights at harvest.
7. While conducting the varietal trials, comparative data on cold and wind resistance as well as disease and insect resistance should be collected. Data also should be taken on percent of fiber in cane and the juice composition studied in terms of calcium, magnesium and phosphorus since all three of these are of considerable economic importance during the milling of the cane and the processing of its sugar.
8. Because of its importance in regard to the availability of both major and minor essential elements to sugar cane, the soil reaction of each 40 acre block of land to be planted should be studied closely. Soils yielding the highest returns in the Everglades now have a pH range from 4.5 to 5.9. Soils with pH readings above 6.0 usually require sulphur applications at planting time in the planting furrows, the quantity varying from 200 to 600 pounds per acre, depending on the pH. Soils on the very acid side below pH 4.0 may require applications of dolomitic limestone for correction.
9. Cane varieties immune to any or all strains of mosaic disease should be selected in preference to susceptible ones.
10. Varieties susceptible to ratoon stunt virus should be strictly avoided. Preference should be given always to cane varieties which not only germinate quickly and well but will ratoon satisfactorily for at least 4 or 5 years.
11. Preference should be given to early maturing, late flowering or non-tasseling varieties which will hold their maximum sucrose content after reaching maturity for at least three and one-half months after January 1, even after being frozen.
12. Preference should be given varieties whose foliage and growing point are especially resistant to frost damage during the fall and winter. This quality is associated with varieties which, after late summer and fall planting, will carry through winters without loss of stand due to repeated frosts. Furthermore, by not being cut back to the ground by frost, such varieties will have a better chance for a longer growing season, mature earlier and obviously yield much higher returns per acre than frost-susceptible types.
13. Studies on the prevalence in the soil of wireworms, especially *Melanotus communis* and white grubs of the *Cyclocephala* and *Phyllophaga* genera should be made while preparing the land. If either or both are prevalent then the open furrows at planting time should be treated with 3 pounds Aldrin in 50 gallons water per acre, before covering the seedpieces.

14. Varieties known to be appreciably susceptible to the moth borer (*Diatraea saccharalis*) should be avoided.
15. Varieties known to be very susceptible to the lesser corn stalk borer (*Elasmopalpus lignosellus*) should be avoided.
16. A regular program of rodent control should be practiced using such poisons as alkaloid strychnine and zinc phosphide on attractive grain baits. All fields should be examined at least three times between late spring and the fall harvest and baited each time if infestation and damage indicates the need for it. Special attention should be given to ditch banks. Cotton and rice rats are most common in the cane fields of south Florida.

Increasing the Effectiveness of Ionizing Radiations in Inducing Mutations[1]

A. T. WALLACE[2]

The dream of research scientists who use mutagens for plant improvement is to be able to induce a specific mutation at will. The ability to so direct mutations would allow animal and plant breeders to change these organisms so they could adapt to any specific environment. The benefits of such manipulation would be so great that a tremendous amount of research is currently being aimed at learning how such mutations can be directed.

It is possible to talk about mutation direction at several levels. When Muller (15) first induced mutations in *Drosophila* with ionizing radiations, he was, to a limited degree, directing mutations. If one uses modifying treatments with ionizing radiations to achieve a higher ratio of point mutations to chromosome aberrations, he is also to a limited degree directing mutations. If one obtains a mutagen that will increase the frequency of gene mutations to a level at which he can select specific mutants with his selection procedure, he is again directing mutations. This is true also if one gets a different spectrum of mutations with different mutagens. Of course, all of these are directing mutations only to a limited degree and are far removed from the precise ability of inducing a specific mutation in a specific gene at will.

This report presents the results from seven experiments designed to test the interaction of modifying agents and gamma rays in the production of mutations at a single locus in oats. The objective of these experiments was to obtain results at only one of the above mentioned levels of mutation direction, *i.e.*, to increase the frequency of gene mutations in surviving progeny.

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REVIEW OF LITERATURE

In recent years a great body of literature—many research articles, review articles, and books—have been published concerning the effects of modifying agents on the radiosensitivity of seeds. Thus no attempt will be made in this article to review all this literature. Generally, the criteria of radiosensitivity reported have been seedling heights, chromosome aberrations, and chlorophyll deficiencies. Very few publications have been concerned with induced mutation rates at a specific locus and the influence of modifying agents on this rate. Unfortunately, also, the induced mutation-rate research with *Drosophila* (18) and mice (1) is limited because these organisms cannot be subjected to all of the same treatments with modifying agents as seed. These organisms will not survive such treatments as soaking or heating to high temperatures.

The number of factors influencing the radiosensitivity of seed is great. Nilan (16) presents a review that covers ten such factors. They are genotype, age, stages of cell division, chromosome number, moisture, temperature, gases, storage, chemicals, and ionization density. Of course, none of these factors is independent in its effects. Much work (3,6,7,9,20) has shown that they tend to interact in influencing the radiosensitivity of seeds. That these factors do influence the radiosensitivity of seeds indicates that there is an interval of time between the actual ionization and the finalization of the mutation event. Research results show that influences during this interval of time may increase the frequency of mutations without increasing chromosome aberrations.

Caldecott (2) has shown that with post-irradiation storage or hydration of barley seeds in the presence of oxygen, seeds are more damaged than if they were stored or hydrated in the absence of oxygen. The presence of oxygen will also increase the frequency of chlorophyll deficiencies (3). Glass and Mettler (11) cited by Conger (5) have presented results with *Drosophila* to indicate that the oxygen effect applies to "point" mutations as well as to chromosome aberrations. The influence of temperature on radiosensitivity of seeds has been investigated by a number of people (16). Ehrenberg and Lundquist (8) demonstrated that the frequency of chlorophyll deficiencies was greater when barley seeds which had been x-rayed were germinated at 5 C, as compared with 20°C. Smith and Caldecott (19) have shown that the frequency of chromatin bridges in root-tip cells of barley was reduced by half when the dormant seeds were subjected to a sub-lethal heat treatment either immediately before or immediately after exposure to x-rays. In addition, chlorophyll deficiencies were increased by the heat exposure (4). The heat treatment after irradiation stimulated the greatest increase in mutation frequency. On the other hand, Kaplan (12) irradiated dry, dormant barley seeds at 17°C and −65 C and found no difference in chromosomal aberration and gene mutation frequency. Caldecott (3) has shown that removing oxygen during storage is more effective in reducing x-ray damage than heating the seed, but the combination of heat plus oxygen removal gives an even greater protection to x-ray damage.

Swaminathan and Natarajan (21) have shown that when wheat seeds are exposed to ultraviolet light prior to x-ray irradiation, the frequency of chromosome aberrations in root meristems was increased. However, the combination of x-rays and ultraviolet light produced a lower frequency of mutations at the lower doses of x-rays and a higher frequency of mutations at the higher doses of x-rays than for x-rays alone. Swanson (22) has shown

that a combination of U.V. x-ray treatments gave a higher frequency of mutations in *Aspergillus terreus* than x-rays alone. These results are supported by other data (13), which also indicates that a combination of x-rays and ultraviolet light tends to increase the frequency of chromosome aberrations.

MATERIALS AND METHODS

The procedure used for these experiments has been previously reported (23). Briefly, it consists of a modification of the Wheeler and Luke (24) technique, whereby toxin produced by *Helminthosporium victoriae* (Meehan and Murphy) is sprayed on germinating Victorgrain oat seeds and surviving seedlings selected which resulted from spontaneous mutants at the locus. In all of our experiments genetically identical seeds from the Victorgrain variety were used. Cobalt-60 gamma rays were used for irradiation at an intensity of about 4 Kr minute. All seeds from all experiments were stored for 24 hours at room temperature after being irradiated before being planted. All plants were grown in isolation.

In experiment 1, seeds with 10% moisture were irradiated at 5 dosage levels to obtain the base induced mutation rate. In experiment 2, seeds at 10% moisture content were irradiated in the absence of oxygen (presence of nitrogen), and either stored in nitrogen or air for 24 hours before being planted. In experiment 3, seeds were dried either to 6.8% moisture content (over silica gel) or to 3.5% moisture content (over P_2O_5) and irradiated. Half of the seeds with 6.8% moisture were wet immediately under a vacuum. These wet seeds, plus the other dry seeds (including the 3.5% seeds) were stored 24 hours and then planted. In experiment 4, seeds were soaked for different periods of time and at different temperatures before being irradiated. The soaking periods and temperatures before irradiation were one hour at 50 C, 24 hours at 2 C, 24 hours at 22°C, and 8 hours at 22°C. In experiment 5, seeds were cooled to dry ice temperature beforehand and kept at this temperature during irradiation. The seeds were stored at room temperature 24 hours before being planted. In experiment 6, seeds were heated to 85°C for one hour either immediately before or immediately after being irradiated. In experiment 7, the de-hulled seeds were exposed (germ side up) to ultraviolet light (112 ergs/mm²/sec.) for one hour before being irradiated. The second generation seeds from these treatments were screened for induced mutants at the *Vb* locus as described by Wallace and Luke (23).

RESULTS AND DISCUSSION

The results from all seven experiments are presented in Tables 1-7. These tables include the dosages used, the number of panicle-progenies tested, the percent of panicles mutated, and the 90% confidence intervals. It should be pointed out that because of low yield of mutations, the confidence intervals for such data are usually quite large. Thus, the results from the various treatments are frequently not significantly different. In order to get truly significant difference in such cases many thousand panicle-progenies will need to be tested. However, the amount of labor necessary for such experiments is almost prohibitive. Consequently, only exploratory experiments have been conducted to obtain trends. Experiments which

TABLE 1.—BASIC GAMMA RAY INDUCED MUTATION RATES AT THE VB LOCUS IN OATS (SEED MOISTURE CONTENT = 10%)

Dose (Kr)	Number panicle progenies tested	Percent panicles mutated	90% confidence interval
0	3248	0	0-0
10	5734	0.018	.001-.093
20	4734	0.169	.084-.304
30	5709	0.228	.136-.362
40	5286	0.208	.117-.344
50	6334	0.063	.021-.144

are much larger are being designed to test thoroughly some of the indications present in the results from the experiments reported here.

The results from experiment 1, presented in Table 1, which was aimed at determining the induced mutation rate under standard conditions (room temperature and 10% moisture content in seeds) show that the highest induced rate was produced at 30-40 Kr. This rate is slightly greater than 0.2% of the panicles tested. Thus, if any modifying agent is to be considered in a mutation breeding program, it will have to increase the efficiency of ionizing radiations so that they will produce a mutation rate greater than 0.2%.

The results from experiment 2, presented in Table 2, which was aimed at determining the effects of anoxia during and after irradiation, show that at 10 Kr there tends to be a higher mutation rate with an absence of oxygen during irradiation than with its presence.

These results seem to be in direct conflict with the results of other workers (3,11) who used the frequencies of chlorophyll deficiencies as the criteria of measurement. The interpretation of such results is not clear and we feel that the experiment should be repeated.

The results from experiment 3, presented in Table 3, which was aimed at determining the effects of low moisture content during irradiation, demonstrate that at low moisture contents (below 10%) the induced mutation rate is higher than at a 10% moisture content. Other research (2,3) has shown this to be true with chromosome aberrations and chlorophyll deficiencies. The 1.5% mutation rate at 5 Kr with seeds of 3.5% moisture content seems to be unusually high. We need to repeat this experiment.

TABLE 2.—EFFECT OF OXYGEN ON GAMMA RAY INDUCED MUTATION RATES AT THE VB LOCUS IN OATS.

Dose (Kr)	Number panicle progenies tested	Percent panicles mutated	90% confidence interval
(a) Irradiated in nitrogen and stored in air			
10	2031	0.246	.097-.517
20	2175	0.000	0-0
30	1880	0.213	.072-.487
(b) Irradiated in nitrogen and stored in nitrogen			
10	1945	0.411	.205-.742
20	2024	0.198	.067-.452
30	1450	0.069	.003-.328

TABLE 3.—EFFECTS OF LOW MOISTURE CONTENT OF SEEDS ON GAMMA RAY INDUCED MUTATION RATES AT THE VB LOCUS IN OATS.

Dose (Kr)	Number panicle progenies tested	Percent panicles mutated	90% confidence interval
(a) Seeds at 6.8% Moisture at time of irradiation and stored for 24 hours dry.			
10	2865	0.244	.114-.459
20	1671	0.359	.243-.738
30	1320	0.076	.003-.360
(b) Seeds at 6.8% moisture at time of irradiation but wet immediately after irradiation.			
10	2620	0.076	.013-.240
20	2347	0.256	.112-.504
30	2334	0.171	.057-.393
(c) Seeds at 3.5% moisture—no wetting			
2.5	1393	0.503	.235- .944
5.0	699	1.573	.883-2.605
10.0	131	0.000	0-0
20.0	18	0.000	0-0

The results from experiment 4, presented in Table 4, show that the induced mutation rate in seeds with higher moisture content is not as high as in seeds with low moisture content, provided that the metabolic activity is not stimulated by the high moisture content. When the metabolic activity is increased, the mutation rate goes up, as do the chromosome aberration and chlorophyll deficiency rates (7).

The results from the experiment aimed at measuring the effects of dry ice temperatures (−78°C) during irradiation, presented in Table 5, show that such temperatures are of no benefit in increasing the induced mutation rate over that shown for normal conditions (Table 1). It should be mentioned that no attempt was made to remove the oxygen or carbon dioxide from these seed during irradiation.

TABLE 4.—EFFECT OF SOAKING SEEDS AT DIFFERENT TEMPERATURES FOR DIFFERENT LENGTHS OF TIME ON GAMMA RAY INDUCED MUTATION RATES AT THE VB LOCUS IN OATS.

	Percent panicles mutated			
Dose (Kr)	Soaked 1 hr. at 50°C	Soaked 24 hrs. at 2°C	Soaked 24 hrs. at 22°C	Soaked 8 hours at 22°C and stored 8 hrs. at 2°C[1]
1.0	--------	--------	0.000	0.000
1.5	--------	--------	0.000	0.546
2.0	--------	--------	0.046	0.500
2.5	--------	--------	0.340	2.339
4.0	0.107	0.000	--------	
6.0	0.050	0.059	--------	
8.0	0.044	0.056	--------	--------
10.0	0.000	0.103	--------	--------
12.0	0.133	0.137	--------	

[1]About 200 panicles per treatment, whereas other treatments had about 2000 panicles.

TABLE 5.—EFFECT OF DRY ICE TEMPERATURES DURING IRRADIATION ON GAMMA RAY INDUCED MUTATION RATES AT VB LOCUS IN OATS.

Dose (Kr)	Number panicle progenies tested	Percent panicles mutated	90% confidence interval
10	2245	0.045	.002-.212
20	2058	0.097	.017-.305
30	1691	0.059	.003-.281
40	1881	0.053	.003-.252
50	1857	0.162	.044-.417

The results from experiment 6, presented in Table 6, show that dry heat (at 85°C for one hour) before or after irradiation tends to increase the induced mutation rate. Post-irradiation heat seems to be the most effective. This observation fits with the published research results on chromosome aberrations and chlorophyll deficiencies (3).

A combination of ultraviolet light and gamma rays produces a higher rate of induced mutations (results presented in Table 7) at 10 Kr than do gamma rays alone. Because of its low penetrating ability, ultraviolet light will not induce mutations in seed unless the layers of tissue covering the embryo are removed (14). Yet when the seeds are exposed to ultraviolet light before they are irradiated with gamma rays, the mutation rate is increased. At the 20 and 30 Kr doses of gamma rays, apparently the combination of these two treatments is so drastic that no cells carrying an induced mutation survived.

The reduction in induced mutation rate at the higher doses of irradiation seems to result from cell survival within multicellular tissue such as seeds. It has also been reported in mutation studies with mice (17). For at least four reasons it is logical to expect that within a seed there must be a differential elimination of cells and thus a reduction in mutation rate at higher dosages of irradiation:

(1) The frequency of chromosome aberrations increases exponentially with increasing dosage;

(2) The likelihood of survival of a cell is inversely related to the number of chromosome aberrations contained in it;

TABLE 6.—EFFECTS OF DRY HEAT, GIVEN PRE- AND POST-IRRADIATION, ON GAMMA RAY INDUCED MUTATION RATES AT THE VB LOCUS IN OATS.

Dose (Kr)	Number panicle progenies tested	Percent panicles mutated	90% confidence interval
(a) Seeds heated to 85°C one hour before irradiation.			
10	1627	0.035	.018-.168
20	2367	0.285	.134-.534
30	2299	0.082	.015-.255
(b) Seeds heated to 85°C one hour after irradiation.			
10	2819	0.246	.084-.562
20	2458	0.127	.034-.328
30	2448	0.217	.087-.456

TABLE 7.—EFFECT OF EXPOSING SEED TO ULTRAVIOLET LIGHT FOR ONE HOUR BEFORE IRRADIATION ON GAMMA RAY INDUCED MUTATION RATES AT THE VB LOCUS IN OATS.

Dose (Kr)	Number panicle progenies tested	Percent panicles mutated	90% confidence interval
10	1883	0.319	.138-.629
20	1250	0.000	.000-.000
30	946	0.000	000- 000

(3) Some seeds are made up of many cells that probably are heterogeneous; and

(4) A number of physical and biochemical factors are known to influence radiosensitivity.

Gaul (10) has presented several suggestions for handling data collected in mutation studies.

The term "mutation" as used in this report refers to changes in expression at one locus in oats. Since the oat species used in these studies is a polyploid, some of the expressions could result from chromosome aberrations. However, these results, expressed in the tables on a percentage basis, when calculated on a per roentgen basis, are in the same frequency range as those reported by Russell with mice (18) and by Alexander with *Drosophila* (1). These two workers have assumed that they were observing point mutations. Although it is known that the frequency of induced and spontaneous mutations vary with specific loci, we are safe in assuming that to a large degree the results reported in this paper are from "point" mutations. At any rate, the results presented here indicate that the induced "mutation" rate in seeds can be modified with pre- or post-irradiation treatments. Furthermore, one can conclude that certain combinations of treatments can be determined that will allow a relatively high rate of mutations to be induced in economic crops.

SUMMARY AND CONCLUSIONS

Seeds of the Victorgrain variety of oats, which are susceptible to the fungus *Helminthosporium victoriae*, were given a series of treatments either before and/or after being irradiated with Cobalt-60 gamma rays and then grown to maturity in isolation. The germinating seeds in the X_2 generation were screened for induced mutations at a specific locus. The highest induced mutation rate with normal seeds at 10% moisture content was about 0.22% of the panicles tested. When the seeds were irradiated in nitrogen, this rate was 0.25%. When the seeds were irradiated in nitrogen and stored in nitrogen for 24 hours after irradiation, the rate was 0.41%. The highest rate obtained with seeds of 6.8% moisture was 0.36% and with seeds of 3.5% moisture was 0.50%. Soaking the seeds at 2°C before irradiation, which keeps the metabolic activity inhibited, did not increase the mutation rate over the normal seeds. However, when the seeds were soaked at 22°C, the mutation rate increased to about 0.5%. On the other hand, when seeds were irradiated at "dry ice" temperature, the highest induced mutation rate was only 0.16%. If the seeds were heated to 85°C for one hour before irradiation, the rate was 0.28%. When heated to 85°C for one hour after irradiation, the rate was 0.25%. By exposing the seeds to ultraviolet light

for one hour before irradiation with gamma rays, a mutation rate of 0.32% was obtained.

These results lead one to conclude that the induced mutation rate with gamma irradiation can be modified by pre- or post irradiation treatments. Furthermore, with additional research certain combinations of treatments may be determined which will allow the induction of a mutation rate in oats at the *Vb* locus as high or higher than 1%.

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Expressions of Heterosis in Intervarietal Crosses of Cigar-Wrapper Tobacco[1]

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The utilization of heterosis in F_1 hybrids involving inbred lines of corn has been responsible for impressive yield increases in this crop for a number of years. In addition, commercial use of F_1 hybrids in the production of onions, tomatoes and eggplants has found wide acceptance. Hybrids with a commercial potential have been developed in several other horticultural crops and ornamental species, however, the high cost of seed production has limited their use.

Most of the instances in which F_1 hybrids have been employed involved the reproductive part of the plant as the portion of commercial importance, with heterosis being expressed as increased yield, uniformity and/or earliness. A short vegetative period followed by a long reproductive period is understandably advantageous in these plants. The commercially important portion of the tobacco plant, however, is restricted to the leaves, so that heterosis expressed as more vigorous or prolonged vegetative growth is necessary before F_1 hybrids can be considered in the production of this crop.

Tobacco is relatively easy to pollinate and produces a large number of seed from each pollination. These factors would be very advantageous if the commercial utilization of F_1 hybrids was ever found to be economically feasible. Cigar-wrapper tobacco has the additional advantage of demanding a large margin of profit which could effectively absorb the additional cost involved in the production of hybrid seed. Whether F_1 hybrid seed will ever be used commercially in this type of tobacco depends on the manner and degree of the expression of heterosis.

Expressions of hybrid vigor in intervarietal crosses of several types of tobacco have been studied, however, there are no data available on the manifestations of heterosis in intervarietal cigar-wrapper tobacco hybrids. This paper reports the study of the amount of heterosis and its manner of expression in F_1 hybrids between the principal varieties of shade-grown cigar-wrapper tobacco.

REVIEW OF LITERATURE

Tobacco is considered a self-pollinated crop with a small degree of out crossing, depending upon location and method of production. Allard (1), commenting on the expression of heterosis in varietal crosses involving self-pollinated species, stated that the data indicate generally smaller responses than those observed in cross-pollinated crops, although some F_1 hybrids exhibit considerable excess in vigor over the superior parent. In a study of intervarietal crosses of open-pollinated corn varieties, Lonnquist and Gardner (9) reported average heterosis values of 108.5 percent relative to the midparent and 102.8 percent relative to the top parent. Since this

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heterotic response is small compared to that obtained from hybrids involving inbred lines, intervarietal corn hybrids have not attained commercial importance.

First generation hybrids between varieties of tobacco (*Nicotiana tabacum*) have frequently exhibited heterosis, and this has led to the suggestion that intervarietal F_1 hybrids be used on a commercial scale (2), (5), (11), and (20). Heterosis in vegetative growth alone may not be sufficient to justify commercial utilization of F_1 hybrids, however, since rigid standards of quality must be maintained. Many times the quality balance inherent in both parental lines is not improved or even maintained in the hybrid, thus the yield increase is more than offset by the reduction in quality.

Commenting on breeding procedures for tobacco varietal development and improvement, Robinson *et al.* (15) and Smith (18) reported that the accumulation of favorable genes in the homozygous condition appeared to be more desirable than the use of F_1 hybrids.

The amount of heterosis expressed in F_1 hybrids seemed to be related to the amount of genetic disparity in the parental lines (7), (11). Thus for the most part, crosses between varieties representing a single tobacco type would not be expected to exhibit as much heterosis as would crosses involving varieties from different types.

Wallace and Clark (21) investigated the possibilities of the use of an F_1 hybrid in flue-cured tobacco as a means of combining desirable leaf type with root-knot resistance, and also from the standpoint of commercial utilization of heterosis. They found that the hybrids with one exception exhibited heterosis for all characters studied, using the midparent value as the reference point, and that generally, hybrids which resulted from two low yielding varieties were more likely to exhibit a greater degree of heterosis than those from high yielding varieties. None of the F_1 hybrids, however, yielded significantly more than the superior variety in the test. On the basis of their studies these workers concluded that the amount of heterosis for yield, crop value and price per pound was not sufficient and that hybrid tobacco was not economically feasible unless parental lines of more diverse origin were available.

A study of the manner of expression of heterosis in an interspecific hybrid was made by Mann and Weybrew (10), using F_1 hybrids between varieties of *N. tabacum* and one of its progenitor species *N. sylvestris*. On the basis of their research they concluded that early maturity and a faster growth rate were the principal manifestations of heterosis in these interspecific hybrids. They further stated that if the results obtained with these hybrids was indicative of what occurs to a lesser extent in intervarietal crosses, early flowering and its effect on leaf production might offset any increase in the growth rate.

Even with these apparent deterrants to the commercial use of F_1 tobacco hybrids, they have been advocated and grown in a number of cases. Toskov and Spasov (20) studied hybrid vigor in the F_1 which resulted from the cross between the varieties Kosarsko 541 x Stanimaka 536. They reported that when compared to the parental varieties the hybrid showed greater height, larger leaves, increased yields, better quality and greater resistance to mosaic and thrips, while retaining the aroma of the Kosarsko 541 parent. In trials with this and nine other hybrids these workers obtained yield increases of 11 to 46 percent without loss in quality.

Popov (12, 13) described the F_1 hybrid which resulted from the cross Virginia Bright x Kosarsko 541 as having a shorter growth period, larger

leaves and 52 percent greater yield than the female parent, combined with the aroma of the pollen parent.

According to Sikka and Batra (17), hybrids from intervarietal crosses of *N. rustica* showed sufficient heterosis in yield and associated characters to make their use feasible on a commercial basis. They reported an increase in yield of 720 pounds per acre of cured leaf for the best hybrid over the standard variety and postulated that the superior performance of the hybrid under changes in environmental conditions may have been due to certain genes controlling competitive abilities which showed overdominance in the heterozygous condition.

Reasons other than the exploitation of heterosis have prompted the use of F_1 hybrids on a commercial basis in other instances. Utilization to facilitate varietal development may be expedient when the situation warrants a rapid change in varietal characteristics, and when desirable attributes controlled by dominant genes are embodied by the selected parental lines. Under these conditions it may be possible to take advantage of increased vigor combined with other desirable characteristics. Coolhaas (3) reported the large scale use of an F_1 tobacco hybrid to combine bright leaf color with normal leaf number, thus synthesizing in one generation a new variety having desirable attributes from two other varieties. He also stated that the same procedure was employed with *Phytophthora*-resistant strains of tobacco.

There are indications that in some instances heterosis could be maintained beyond the F_1 generation. Ioan and Ille (6) reported expressions of heterosis in the F_2 generation of crosses which involved oriental tobacco varieties with regard to yield, quality and chemical composition. Selection of phenotypically stable lines which maintained the degree of heterosis expressed in the F_1 was accomplished by Rave (14).

MATERIALS AND METHODS

Four varieties of shade-grown cigar-wrapper tobacco, Dixie Shade, Rg, Connecticut 49 and No. 63, and six F_1 hybrids involving these varieties in all combinations excluding reciprocals were evaluated at the North Florida Experiment Station. Dixie Shade (8) is the predominant variety in the Florida-Georgia cigar-wrapper area at the present time. (Rg (4), grown extensively from the early 1930's until the release of Dixie Shade in 1953, is still a popular variety and resembles Dixie Shade in many respects. Connecticut 49 (16) and selections from it are grown extensively in the Connecticut Valley cigar-wrapper area, but not in Florida because of susceptibility to black shank. No. 63[3] is a new variety in the Florida-Georgia area which has several advantages in agronomic characteristics and quality over Dixie Shade.

A randomized complete block design with four replications was used, with plots consisting of rows 32 feet in length and plants spaced 12 inches apart in the row. The area was fertilized with a 5-3-5 commercial mixture at the rate of 5000 pounds per acre. Three thousand pounds were applied prior to transplanting and 1000 pounds added as a side dressing at each of two weekly intervals following transplanting.

The characters used for measurements of heterosis were selected be-

[3]No. 63 originated from a cross between Rg and Connecticut 49 made by the American Sumatra Tobacco Corporation and was selected by the North Florida Experiment Station.

cause of their importance in varieties of cigar-wrapper tobacco. Yield and percent high quality tobacco were computed on the basis of entire plots, while measurements on the other characters were made on ten plants from each plot, using the same plants for all measurements. Data were recorded on the characters listed below.

Leaf Area: Measurements of length and width in inches of the fourth and tenth leaves were recorded. These measurements were converted into an estimate of leaf area using the relationship A = (0.6345) (length) (width) (19).

Total Leaf Number: The number of leaves from the first of harvestable size to the last below the inflorescence was recorded just prior to the last leaf harvest.

Number of Leaves Exceeding Sixteen Inches in Length: Starting with the lowest harvestable leaf, the number of leaves exceeding sixteen inches in length was recorded. Sixteen inches was selected as the shortest leaf length of convenient commercial utility.

Height of Last Leaf Exceeding Sixteen Inches in Length: Measurement was made from the soil line to the axle of the highest leaf exceeding the sixteen-inch minimum length.

Internode Length: The internode length in inches was calculated from the data on number and height of the last leaf exceeding sixteen inches in length.

Days from Transplanting to Flowering: An average number of days from transplanting to flowering was estimated by determining the time necessary for 50 percent of the plants in the row to produce flowers.

Yield: The tobacco was harvested by plots, cured and fermented according to standard commercial practices. When fermentation was complete the weight of tobacco from each plot was recorded and yields expressed in pounds per acre.

Percent High Quality Tobacco: Grading was conducted by Experiment Station personnel, using a grade scale designed for experimental tobacco, but so devised that commercial utility could also be expressed. Some of the factors considered in the quality classification included light uniform colors, elasticity, tensile strength, body and grain. This category represents tobacco which would bring the highest prices and be most in demand by the trade.

RESULTS AND DISCUSSION

Heterosis as originally defined was intended to replace the term "heterozygotic stimulation," and is currently used interchangeably with hybrid vigor. It is well known that not all F_1 hybrids exhibit hybrid vigor, and some workers employ the term negative heterosis to describe instances when the F_1 falls below the parental mean for a particular character. Heterosis in current usage means the increased vigor of the F_1 over either the mean of the parents or over the top parent.

In considering the exploitation of heterosis on a commercial basis from the plant breeders point of view it is evident that the definition must be restricted to an increase in character expression over the top parent, for if this were not achieved the hybrid would have no real advantage over either parent in terms of increased vigor. Other instances may be visualized, however, such as a rapid combination of desired characters, when heterosis may not be the desired objective in an F_1 hybrid.

The principal agronomic characteristics of the intervarietal F_1 hybrids

are compared with the respective parental varieties in Table 1. With the exception of the hybrid in Family C involving Dixie Shade and Rg, all exceeded the midparent value for yield. When considering the top parent as the reference point, four of the six hybrids exhibited heterosis, with the hybrid in Family D having the greatest yield increase (180 lbs.). It can be seen in comparing varietal yields that the parental lines in Family D (No. 63 and Dixie Shade) were ranked first and second, respectively in yield among the varieties.

Five out of the six hybrids produced a yield of high quality tobacco exceeding the average of their respective parental lines, while four out of six were superior to the top parent in this character.

Every hybrid exceeded the midparent value for the characters fourth and tenth leaf area. The top parent value was surpassed by five of the hybrids for fourth leaf area and by three for tenth leaf area, with the hybrid in Family D (No. 63 x Dixie Shade) producing the greatest difference in both of these characters.

Total leaf number and number of leaves greater than sixteen inches in length were very similar in heterotic expression. The Family B hybrid (Dixie Shade x Conn. 49) exceeded both midparent and top parent values for both these characters, and Family F (No. 63 x Conn. 49) exceeded the midparent value only for total leaf number. All other hybrids failed to surpass midparent values in their respective families.

The height of the last leaf greater than sixteen inches in length is a function of both leaf size and plant height. All hybrids were superior to the midparent value for this character, and five out of the six families had hybrids exceeding the top parent. The superior family was D (6.9 in.) followed by B (5.5 in.) and F (4.6 in.).

The midparent values for internode length, also associated with plant height, were surpassed by every hybrid, while five families had hybrids which exceeded the top parent for this character.

Four of the six hybrids flowered earlier than the average of the parents and two later than the parental mean. Only one hybrid (Dixie Shade x Conn. 49) flowered later than the latest flowering parent. Mann and Weybrew (10) also observed earlier maturity in hybrids and suggested that earlier flowering and its consequent effect in reducing number of leaves might offset other advantages of hybrid tobacco.

It is evident from the data that heterosis for all nine characters studied is not expressed to the same degree and not necessarily in every hybrid. A summary of the number of instances where the hybrid exceeded the midparent and top parent values is presented in Table 2. Four of the nine characters exceeded the midparent value in all six hybrids. Two of these characters, height of last leaf greater than sixteen inches in length and internode length, are functions of plant height. The other two, area of fourth and tenth leaves, may have an effect on yield if this performance is representative of other leaf positions. This seems to be indicated, since five of the six hybrids exceeded their respective midparent values for yield. Total number of leaves greater than sixteen inches in length and days to flower exceeded the midparent value in only one hybrid (Dixie Shade x Conn. 49). The hybrid in Family D actually flowered sooner than the earliest parental variety.

The expression and degree of heterosis may vary in different hybrids depending on the parental lines involved. It has been shown with a number of plants that heterosis increases directly with diversity between parental

TABLE 1.—COMPARISON OF SIX F_1 CIGAR-WRAPPER TOBACCO HYBRIDS WITH THEIR RESPECTIVE PARENTAL LINES FOR NINE CHARACTERS.

Family	Variety or hybrid	Yield (lbs./A)	% High quality tobacco	Area 4th leaf (sq. in.)	Area 10th leaf (sq. in.)	Total leaf number	No. leaves 16″ length	Height last leaf 16″ length	Internode length (in.)	Days to flower
A	Conn. 49	1674	65	146.9	159.0	24.4	20.6	76.5	3.7	55
	Rg	1656	60	182.4	195.2	24.7	20.6	87.6	4.3	61
	Conn. 49 x Rg	1702	73	169.2	179.0	23.7	19.9	86.8	4.4	57
B	Dixie Shade	1690	72	183.7	182.6	24.0	19.3	84.4	4.4	61
	Conn. 49	1674	65	146.9	159.0	24.4	20.6	76.5	3.7	55
	Dixie Shade x Conn. 49	1719	77	191.9	192.6	26.2	21.3	89.9	4.2	62
C	Dixie Shade	1690	72	183.7	182.6	24.0	19.3	84.4	4.4	61
	Rg	1656	60	182.4	195.2	24.7	20.6	87.6	4.3	61
	Dixie Shade x Rg	1699	66	205.1	191.7	24.2	19.6	89.2	4.6	61
D	No. 63	1790	79	173.5	177.2	26.7	22.4	82.5	3.8	69
	Dixie Shade	1690	72	183.7	182.6	24.0	19.3	84.4	4.4	61
	No. 63 x Dixie Shade	1970	80	208.1	215.7	23.9	20.1	91.3	4.5	59
E	No. 63	1790	79	173.5	177.2	26.7	22.4	82.5	3.8	69
	Rg	1656	60	182.4	195.2	24.0	20.6	87.6	4.3	61
	No. 63 x Rg	1744	68	182.5	192.9	24.0	20.2	87.9	4.4	61
F	No. 63	1790	79	173.5	177.2	26.7	22.4	82.5	3.8	69
	Conn. 49	1674	65	146.9	159.0	24.4	20.6	76.5	3.7	55
	No. 63 x Conn. 49	1879	82	170.6	186.7	25.8	21.3	87.1	4.0	55
	L.S.D. (.05)	158	11	19.6	16.1	1.5	1.3	3.9	1.2	4
	L.S.D. (0.1)	214	15	26.7	21.9	2.0	1.8	5.4	1.7	6
	C.V. (%)	5	9	6	5	4	4	3	3	4

TABLE 2.—TOTAL NUMBER OF TIMES THE SIX F_1 CIGAR-WRAPPER TOBACCO HYBRIDS EXCEEDED THE MIDPARENT OR TOP PARENT VALUE FOR THE NINE CHARACTERS STUDIED.

Character	Above Midparent	Above Top parent
Yield	5	4
% High quality tobacco	5	4
Area 4th leaf	6	5
Area 10th leaf	6	3
Total leaf No.	2	1
Total leaves 16″	1	1
Heigh leaf 16″	6	5
Internode length	6	5
Days to flower	1	1

lines. Heterotic response of the six hybrids investigated with regard to the nine characters considered is shown in Table 3. Hybrid B (Dixie Shade x Conn. 49) exceeded the midparent value for all nine characters under investigation, and the top parent value for eight of the characters. The amount of genetic disparity between parental lines is perhaps greater in this family than any other, with the possible exception of Family A (Conn. 49 x Rg). Dixie Shade and Rg are very similar in appearance, agronomic characteristics, yield and quality; however, slight genetic differences may account for better combining ability of Dixie Shade in Family 8. That Dixie Shade and Rg are similar in genetic constitution is indicated since Hybrid C only exceeded the midparent value for five characters and the top parent value for three characters.

No. 63 was developed from a cross involving Rg and Conn. 49, thus the parental lines of both Hybrids E and F can be assumed to have a degree of generic similarity. This is borne out strongly in Hybrid E with fewer heterotic expressions, however, Hybrid F exhibited wider character expression. This may indicate greater selection pressure toward the Rg type in the development of No. 63. Once again Dixie Shade appeared to be a better combiner that Rg in Hybrid D as compared with Hybrid E.

Heterosis in intervarietal crosses of cigar-wrapper tobacco is most often expressed in greater plant height and larger leaves, followed by increased yield and better quality. Two of these characters may be interrelated, since larger leaves can result in greater yield. These heterotic manifestations are of course governed by the varieties used as parents. It is also apparent that

TABLE 3.—TOTAL NUMBER OF TIMES THE NINE CHARACTERS EXCEEDED THE MIDPARENT OR TOP PARENT VALUES FOR THE SIX F_1 CIGAR-WRAPPER TOBACCO HYBRIDS.

Family	Hybrid	Midparent	Top parent
A	Conn. 49 x Rg	6	2
B	Dixie Shade x Conn. 49	9	8
C	Dixie Shade x Rg	5	3
D	No. 63 x Dixie Shade	6	6
E	No. 63 x Rg	5	3
F	No. 63 x Conn. 49	7	6

the amount of hybrid vigor for each of these characters would not necessarily increase at the same rate. Parents which have great genetic dissimilarity might produce a hybrid having greatly increased height and vegetative growth but with very poor quality compared with the most desirable parent.

Increased plant height may be a disadvantage in cigar-wrapper tobacco. The top leaves of established varieties are frequently not readily accessible because of their height on the stalk. Since heterosis for this character seems common in tobacco hybrids it may be a limiting factor if commercial use of an F_1 cigar-wrapper tobacco hybrid is ever anticipated.

Of equal importance in considering commercial F_1 hybrid production is the frequent occurrence of early flowering. It is not uncommon for the hybrid to flower before the earliest flowering parent, as was the case in Family D. Early flowering, while advantageous in some crops, is undesirable in tobacco since the plant ceases to initiate and develop leaves once the reproductive phase starts. A decrease in leaf size and a definite reduction of quality is also associated with the onset of the reproductive process.

Before the commercial use of an F_1 tobacco hybrid can be recommended on the basis of heterosis alone, the amount of increased vigor in yield, quality and other important characteristics must be great enough to more than offset the increased cost of seed production. A further requirement would be that the characteristics of the hybrid could not be easily obtained in a pure line variety. The performance of the varietal hybrids in percent of the midparent and top parent values for the nine characters studied is presented in Table 4. These percentages are averages of the six families for the nine characters. The percent heterosis above the midparent for yield, leaf area and high quality tobacco, while rather small compared with hybrids in some other crops indicates that increased vigor for commercially important characters can be achieved. The values for yield (104.5 percent and 102.5 percent above the midparent and top parent, respectively) are quite comparable to those obtained for intervarietal corn hybrids (108.5 percent and 102.8 percent) by Lonnquist and Gardner (9). An increase in plant height and a decrease in number of days from transplanting to flowering are undesirable expressions of heterosis in tobacco. Flowering response in the hybrid may be considered an example of negative heterosis since the hybrid flowered before the average of the parents.

TABLE 4.—AVERAGE PERFORMANCE OF THE SIX F_1 CIGAR-WRAPPER TOBACCO HYBRIDS EXPRESSED AS PERCENT OF THE MIDPARENT AND TOP PARENT VALUES FOR THE NINE CHARACTERS STUDIED.

Character	Mean F_1 performance % relative to Midparent	Top parent
Yield	104.5	102.5
% High quality tobacco	108.8	100.4
Area 4th leaf	109.4	103.4
Area 10th leaf	108.3	103.0
Total leaf No.	98.9	96.2
Total leaves 16″	98.6	95.2
Ht. leaf 16″ in length	107.2	103.6
Internode length	106.6	102.0
Days to flower	95.7	89.7

The commercial potential of a hybrid is indicated by its performance relative to the top parent. The percent increase of commercially important characters decreased considerably, with the amount of high quality tobacco being reduced the most. A significant point is the reduction in days to flower by 10.3 percent below the top parent. The reduction in yield when compared to the better parent may be due, among other things, to an earlier occurrence of the reproductive process.

At the present time there are no officially released commercial F_1 tobacco hybrids in production. Considering the data presented it seems unlikely that an F_1 hybrid involving currently available cigar-wrapper tobacco varieties will ever attain significant commercial importance. It has been shown with corn and several other crops that inbreds used as parents vary widely in ability to produce outstanding hybrids. To utilize heterosis on a commercial basis it will be necessary to develop lines which, by virtue of their combining ability when crossed, produce a hybrid that excels in yield, quality and other desirable characteristics with a minimum of vigor for undesirable characters. This will involve the testing of many breeding lines, both for desirable agronomic characteristics, yield and quality, and for superior combining ability.

SUMMARY

Six F_1 hybrids involving four varieties of shade-grown cigar-wrapper tobacco in all combinations excluding reciprocals were evaluated for manner of expression and amount of heterosis in nine agronomic characters.

Heterosis was most often expressed in greater plant height and larger leaves, followed by increased yield and improved quality. Heterotic responses for yield of 104.5 percent and 102.5 percent relative to the mid-parent and top parent respectively could be accounted for by greater leaf area. The highest F_1 yield (1970 lbs./A) was obtained from hybrid D (No. 63 x Dixie Shade). The percent high quality tobacco in the hybrids only slightly exceeded the top parent value. Earlier flowering exhibited by some of the hybrids was considered with regard to the effect on reducing yield.

Differences in amount of heterosis depending on the divergence of parental lines indicated critical selection of potential parental lines for combining ability is necessary to realize a commercial potential in an F_1 cigar-wrapper tobacco hybrid.

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Recent Advances in Aquatic Weed Control[1]

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The diverse nature and habitat of aquatic plants has resulted in a number of approaches to the control of aquatic weeds. The discovery of 2,4-dichlorophenoxyacetic acid (2,4-D) lead to a considerable amount of research on water hyacinth (*Eichhornia crassipes* (Mart.) Solms) control in 1945 (1, 3, 6, 16). This work encouraged the use of 2,4-D on other aquatic species. Research was initiated in 1946 to study chemical control of submersed aquatic weeds in the west (5). One of the more significant accomplishments of that work was the development of emulsified aromatic solvents for the control of submersed aquatic plants in irrigation channels (4). The same chemicals were adapted for use under Florida conditions by Seale *et al.* (8), and Stephens *et al.* (12). Other aquatic weeds such as cattail have been successfully controlled with 2,4-D (14) and wth 2,2-dichloropropionate (dalapon) and 3-amino-1,2,4-triazole (amitrole) (11, 15). The importance of aquatic weed problems and the progress made in aquatic weed control were summarized by Seaman (10) at the 1958 meeting of this Society. An earlier paper in 1948 had summarized the progress of aquatic weed control up to that time (13).

The expanded interest in aquatic weed control in recent years has brought the potential of this field to the attention of chemical manufacurers and formulators. More than 1,000 chemical compounds were evaluated as aquatic herbicides by the Auburn Agricultural Experiment Station (7) under contract with the U. S. Department of Agriculture, and the U. S. Army Corps of Engineers.

The most promising aquatic herbicides in these preliminary tests have been further evaluated in extensive laboratory and field experiments in Florida. This paper is a brief summary of the methods and results in those studies.

METHODS AND MATERIALS

Aquatic plants are commonly found growing in large volumes of water. When chemical treatments are tested on a parts-per-million basis, large amounts of chemicals are required for evaluation in field experiments. It was necessary, therefore, to develop techniques for secondary testing, which would give reliable evaluations of small quantities of chemicals. Research was initiated at the Plantation Field Laboratory early in 1960 to develop such methods of testing chemicals for control of submersed, emersed, and floating aquatic plants in growthroom and greenhouse studies.

Three species of submersed weeds commonly found in the southeastern United States are used. They include southern naiad (*Najas*

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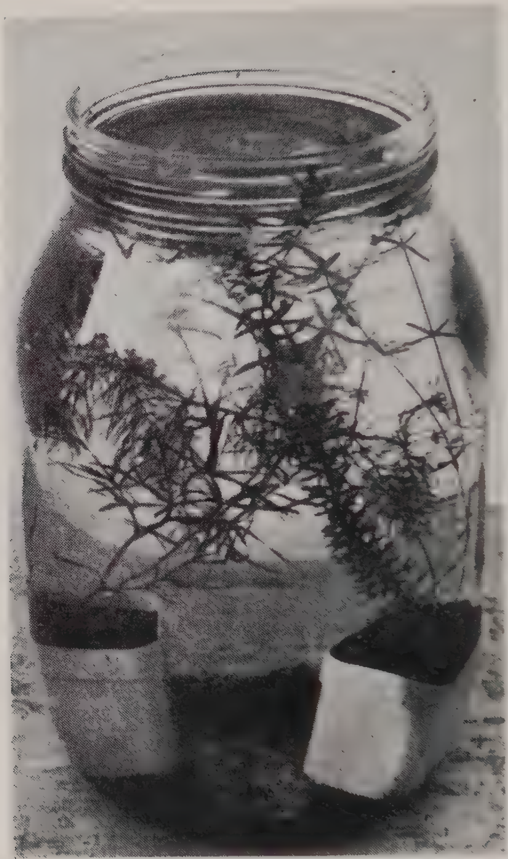

Fig. 1.—A submersed weed test jar showing rooted southern naiad and elodea and unattached coontail.

guadalupensis (Spreng.) Magnus), coontail (*Ceratophyllum demersum* L.), and elodea (*Elodea densa* (Planch.) Caspary). Terminal cuttings of naiad and elodea are planted in small pots of soil which are then placed in a 1-gallon wide-mouth glass jar filled with tap water. A 4 to 6 inch cutting of floating coontail is then added to each jar (Figure 1).

Fertilizer is added and the jars are placed in a room maintained at 80° F with 60 to 80 foot-candles of fluorescent light. The plants are allowed to grow 3-weeks before treatment with the chemical. The chemicals are added to the jars at 1, 5, and 10 parts per million by weight (ppmw) and observations of herbicidal effects are made 4-weeks later.

The most promising chemicals are then tested further in a series of time versus concentration studies. In these studies the plants are allowed to be in contact with the chemical for periods from 0.5 to 336 hours before removal, washing, and placement in untreated water, where they are kept until the evaluation of herbicidal effects 4-weeks after treatment.

The chemicals which prove most active are then evaluated in test canals in the field. The usual method of application is to dilute the chemical in a stock solution of water which is then injected into the canal at the rates which showed promise in the laboratory studies.

Other procedures have been developed for evaluating promising chemi-

cals on floating and emersed weeds. A plastic container (11½" x 8¼" x 12¼" high) is filled with water and the floating plants added. If emersed species are used, they are potted and then placed into the plastic container. The plants are then sprayed with a micro-sprayer on a pound-per-acre basis. Plants used in these containers include alligatorweed (*Alernanthera philoxeroides* (Mart.) Griseb.), water hyacinth, water lettuce (*Pistia stratiotes* L.), and water fern (*Salvinia rotundifolia* Willd.) (Figure 2). The chemicals found promising in laboratory evaluation studies are then tested on these species under field conditions. Field experimental techniques on floating weeds usually vary considerably, depending upon the stand of weeds and the nature of the test. The plants may be confined to an area by floating poles anchored to the bank. Stakes driven through the mats of floating alligatorweed into the mud will usually hold the plants in place. The plot size is generally about 0.01 acre but may vary up to several acres in the case of aerial applications. Small plot applications are usually made with hand spray-gun operated from a boat or the bank.

RESULTS AND DISCUSSION

An experiment was conducted in 1960 to test the general effectiveness of several quaternary ammonium compounds on southern naiad. N-dodecyltrimethylammonium chloride (ACA-1), *N*-alkyl methylisoquinolinium chloride (Ammonyx 781), alkyl dimethylbenzyl dimethyl ammonium chloride (BTC 927), and *N*-alkyl dimethyl benzyl ammonium and *N*-alkyl dimethyl ethylbenzyl ammonium chlorides (BTC 2125) were applied at 5 and 10 ppmw, while 1:1'-ethylene 2:2'-dipyridylium dibromide (diquat) was applied at 3 and 5 ppmw. Diquat was definitely the most active chemical in this test. The plants treated with diquat showed chemical effects the second day after treatment, and treated plots were completely free of naiad in about 3 weeks. Naiad from the untreated buffer zones between the 400-foot plots used in this experiment, may have accounted for the small amount of regrowth noted 21 weeks after treatment.

The low fish toxicity of diquat, high solubility in water, and long duration of control at low concentrations lead to further testing in 1961. Several other herbicides which had shown promise in laboratory testing in 1960 were included in two rather complete field tests in 1961, one located in the Homestead area, and the other near Fort Lauderdale. Acrolein, which had shown promise in 1960 field experiments (2) served as a standard treatment. In each of the new experiments, diquat, acrolein, and formulations of 3,6-endoxohexahydrophthalic acid (endothal) were very effective on submersed weeds. Therefore, it was decided to test each of these materials in a large portion of a drainage canal.

Diquat was applied to a large canal 1-mile long at the rate of 5 ppmw on June 22, 1961. The weed species present included southern naiad, coontail, water fern, duckweed, and a branched algae (Pithophora). All of the vegetation slumped to the bottom of the canal in 3 weeks. There was no regrowth 4 months after treatment.

In another area, sections of canal 0.5 miles in length, were treated September 5, 1961, with diquat at 3, 4, and 5 ppmw, and two different formulations of endothal at 3 ppmw. Preliminary observations indicated that all of these rates are effective. It will be several months before final evaluation results from this experiment can be made. The water flow was completely stopped for several days following these treatments, to allow maximum

Fig. 2.—Floating alligatorweed (top) and water lettuce (bottom) growing in the plastic test containers.

TABLE 1.—FIELD EVALUATIONS OF 5 QUATERNARY AMMONIUM CHEMICALS FOR CONTROL OF SOUTHERN NAIAD. CONTROL EXPRESSED AS PERCENT REDUCTION IN ORIGINAL STAND ON SUCCESSIVE EVALUATION DATES AFTER TREATMENT.

Chemical	Rate	Weeks after treatment						
		2	4	6	8	12	16	21
	ppmw	%	%	%	%	%	%	%
ACA-1	5	60	70	70	65	40	15	0
	10	90	96	95	100	65	35	15
Ammonyx 781	5	20	10	0	0	0	0	0
	10	60	55	25	0	0	0	0
BTC 927	5	70	50	40	10	0	0	0
	10	90	95	85	80	50	0	0
BTC 2125	5	50	37	20	5	0	0	0
	10	85	100	90	75	60	10	0
Diquat	3	95	100	100	98	85	85	60
	5	90	100	100	100	93	90	85

control. The endothal formulations gave a much more rapid kill of the weeds which disintegrated within 72 hours. However, these chemicals are quite toxic to fish, while diquat is not.

A number of experiments on water lettuce have been conducted during the past three years. Diquat has been tested at 1, 2, 3, 4, and 5 lb/A. Two experiments conducted in drainage ditches have shown that 1 lb/A is insufficient but that the 3-lb rate gives 97 percent control within 3 weeks. While higher rates are slightly more effective, there is still a slight amount of regrowth from the auxiliary buds which can serve to reinfest the area. Retreatment would probably be required to give complete control. 2,4-D has been included in the experiments at 4 to 8 lb/A with and without diesel oil at 5 to 10 gal/A, applied in water to give 200 gal/A total spray solution. In all cases 2,4-D has not been as effective as diquat.

A recent experiment was conducted to compare diquat, amitrole-T and 2,4-D on a mixed stand of water lettuce and water hyacinth on a large canal area. The treatments were made by airplane on plots 4-acres in size. Diquat was applied at 1, 2, and 3 lb/A; amitrole-T at 1 lb/A; and 2,4-D at 2 and 4 lb/A. The chemicals were applied with 0.1 percent B-1958 emulsifier. 2,4-D was applied in 5 gal/A of oil while the other materials were applied in 5 gal/A of water. Plant kill as observed 2 months after treatment showed that 2,4-D at these rates was quite ineffective on water lettuce, but had given an excellent topkill of water hyacinth. However, regrowth was rapid and 3 months after treatment, control was only 65 percent for the 2-lb rate and 80 percent for the 4-lb rate. Amitrole-T gave 98 percent control of the water hyacinth but was completely ineffective on the water lettuce. Diquat at 3 lb/A resulted in about 80 percent topkill of the water hyacinth but regrowth was rapid. Excellent control of water lettuce was obtained by either the 2- or 3-lb rate of diquat and the 1-lb rate gave 85 percent control (Figure 3).

Another stride forward was the discovery of amitrole-T as an alternate treatment for control of water hyacinth (9). Amitrole-T has consistently given 90 to 100 percent control with single applications of 1 to 2 lb/A in 200 gal/A of water (Figure 4). Two or more applications of an amine salt of 2,4-D at 4 to 6 lb/A are required to give equivalent control. The greater

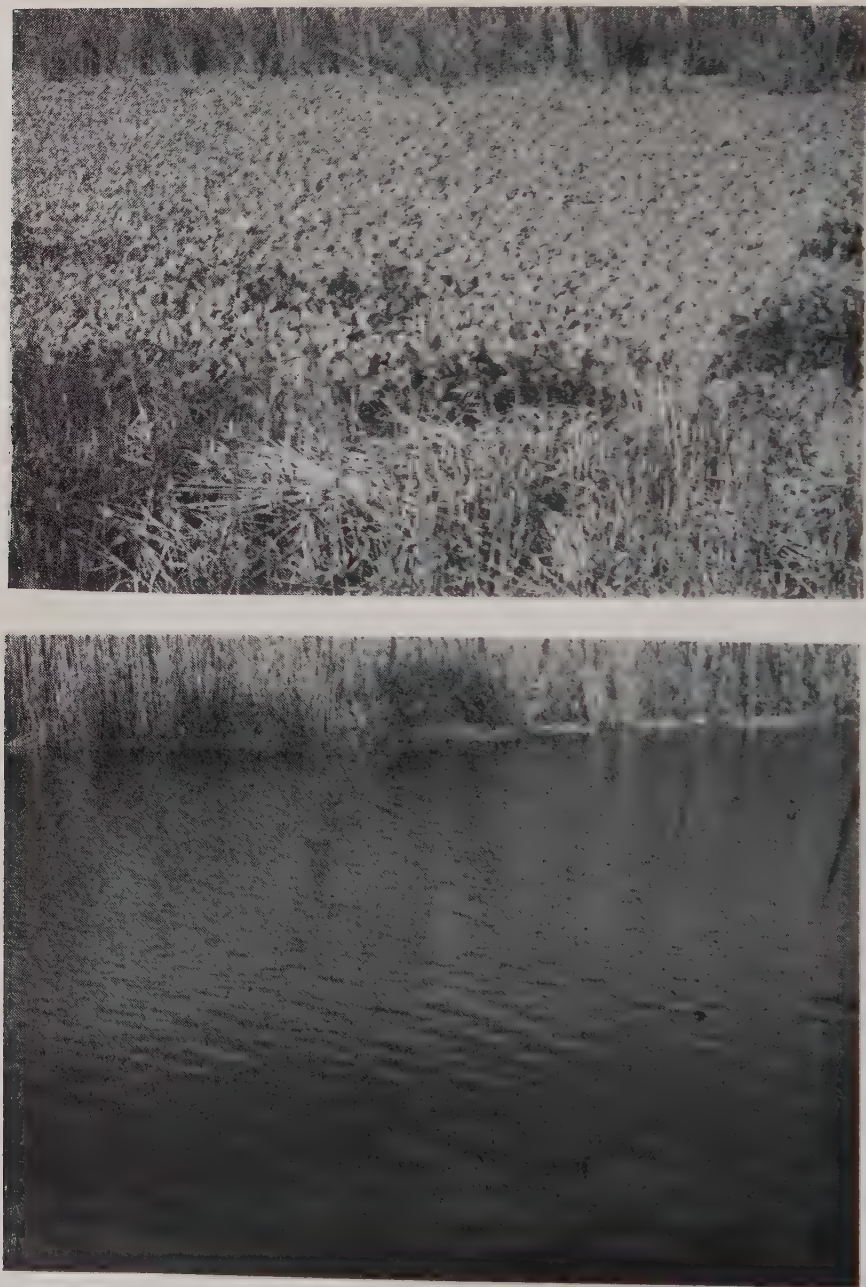

Fig. 3.—The canal covered with water lettuce and water hyacinth (top) which has been treated 1 month previously with amitrole-T at 1 lb/A. Note the blackened condition of the water hyacinth with no apparent effect on the water lettuce. Diquat at 3 lb/A (bottom) gave excellent control as seen 1 month after treatment, but the water hyacinth either floated in from an untreated area or regrew.

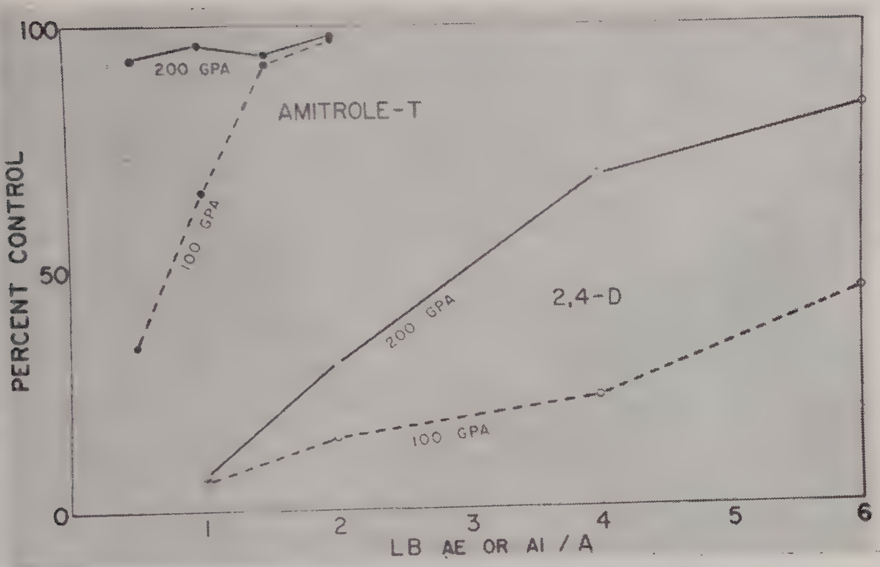

Fig. 4.—Relative control of water hyacinth 3 months after treatment with Amitrole-T and 2,4-D each applied at 100 and 200 gal/A.

translocation of amitrole-T into connecting plants as evidenced by symptoms probably accounts for the longer control without reinfestation as compared with 2,4-D. But the most important advantage is the greater safety of amitrole-T when used near crops. The drift of spray or vapors of 2,4-D will often cause severe damage to surrounding crops while the drift of amitrole-T will not do so.

Other studies are underway to find a means of controlling alligatorweed. An intermediate phase of experimentation is being conducted in growth pools, which are 3 by 9 feet and 2 feet deep. Floating and rooted-emersed alligatorweed are established in the pools before treatment with chemicals which prove most promising in the secondary evaluation previously mentioned. The better treatments in the growth pool experiment are then tested on natural infestations in the field.

2-(2,4,5-trichlorophenoxy) propionic acid (silvex) has shown the most promise on all growth habits of alligatorweed. Stands of alligatorweed rooted firmly in soil are controlled effectively with a granular formulation of silvex at 20 to 40 lb/A. Floating mats of alligatorweed are considerably more difficult to control. It appears that repeated treatments with silvex at 8 lb A will give best control, but treatments may need to be made three to five times. A considerable amount of research is now being conducted on various formulations, derivatives, and rates of application of silvex for control of floating alligatorweed.

The development of primary and secondary evaluation techniques has paved the way for expanded testing of chemicals as aquatic herbicides. It has been shown in laboratory and field tests that diquat and two formulations of endothal offer most promise for the control of submersed aquatic weeds. Diquat, at 2 or 3 lb A, has consistently given excellent control of water lettuce and is fairly effective on water hyacinth. Amitrole-T may have

a role as an alternate method for the control of water hyacinth, especially in areas where 2,4-D would be hazardous to nearby sensitive crops. It appears that of the chemicals which are currently available, repeated applications of silvex offer the best method for control of alligatorweed. These studies are not in any way the final answer but point to the fact that much progress is being made in the field and that greater advancements are anticipated in the future.

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Establishment and Maintenance of Large Turf Areas

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SCOPE OF THE TURF INDUSTRY

During the past 10 years the Florida Turfgrass Industry has emerged into an important segment of Florida's economy. Few industries within the state, except the food industry, affect as many people as turf. The Florida Turfgrass Association, in 1960, estimated the value of turf to the Florida economy to be in excess of $120 million dollars annually, Table I. This is the estimated amount spent on maintenance of Florida's ornamental turf. It does not include the agricultural business aspect of turf management which would more than double this figure.

TABLE 1.—ESTIMATED EXTENT AND VALUE OF THE TURFGRASS INDUSTRY OF FLORIDA

Segment of industry	Number of units	Acreage	Annual Maintenance cost per acre	Annual Cost segment value of
Homes & apartments	1,100,000	200,000	$ 300	$60,000,000
Churches	3,000	4,000	500	2,000,000
Cemeteries	200	21,000	500	10,500,000
Motels	5,500	3,500	1700	5,950,000
Hotels	1,300	500	1700	850,000
Schools	1,200	12,000	200	2,400,000
Parks, all		10,000	300	3,000,000
Golf courses	200	20,000	500	10,000,000
Highway turf		200,000	30	6,000,000
Turf nurseries	100	30,000		20,000,000
Totals		501,000		$120,700,000

In no other state in the United States is the need for outstanding turf any greater than in Florida. This is true for both winter and summer, especially in south Florida. Due to its climate, outdoor activities continue throughout the year.

We owe a good part of our annual income to the tourist business and it is most important that the people enjoy their visits. Since they come down to spend time outdoors, they expect and should see excellent turf.

The largest turf areas in the state are our highway right-of-ways. There are more than 200,000 acres of right-of-way turf that is fertilized and mowed several times a year. About $30 per acre per year is spent on the maintenance of these turf areas. Pensacola bahiagrass is used on 80 to 90 per cent of these areas and it produces a very pleasing effect to motorists who spend many hours on our highways. The safety feature of having the grass on these road shoulders more than justifies the cost of establishment and maintenance. There is no state in the United States that has highway turf equal to that of Florida.

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Tourists, like resident Floridians, enjoy outdoor sports during the entire year and turf is an integral part of most of these outdoor sports. There are more than 200 golf courses with an average of 100 acres per course. This is about 20,000 acres of intensively maintained turf. More than $500 per acre per year is required for maintenance on these large turf areas or approximately $10 million dollars annually. Golf in Florida is enjoying its greatest expansion even with the high value land that tremendously increases the cost of constructing new golf courses. In addition to these golf courses there are State and Federal parks with an estimated 20,000 acres of turf maintained for the enjoyment of tourists and resident Floridians. Not too far removed from recreation are the 5,500 motels and 1,300 hotels that have small to large turf areas that are highly maintained. Many of these maintain putting greens for the guests and all have some turf areas. Add to this more than one million home and apartment lawns with an estimated 200,000 acres of turf on which many thousands of dollars are spent for maintenance yearly.

Our churches, schools and larger businesses use turf for beauty, recreation and utility. These generally consist of small turf areas but when all are added together the total becomes a sizeable figure.

From our early childhood turf is an important part of our life. Even when our span on earth is completed, we are still dealing with turf because many thousands of acres of turf are used to beautify our cemeteries and memorial parks.

Since there are more than 500,000 acres of turf in Florida and many of these are large turf areas, the establishment and maintenance of these areas become important.

ESTABLISHMENT OF LARGE TURF AREAS

Propagation methods for turf establishment are: sodding, plugging, sprigging, broadcasting, disking-in and seeding.
Fortunately, there are several grasses that may be selected for planting. Before any method of planting can be established, the grass selection has to be made. The primary consideration is the intended use of the area. On an exclusive golf course, one of the improved bermudagrasses would be best; however, for a highway right-of-way, Pensacola bahiagrass would be

TABLE 2.—MATERIAL REQUIRED IN PLANTING AN ACRE OF TURF BY THE VARIOUS METHODS

Planting method used	Amount of planting material required Per 1000 sq. ft.	Per acre
Solid sodding	1000 sq. ft.	43,560 sq. ft.
Plugging (partial sodding)		
4-in. plugs—12 in. centers	348 sq. ft.	14,200 sq. ft.
2-in. plugs—12 in. centers	87 sq. ft.	3,800 sq. ft.
¾ in. plugs—12 in. centers	12 sq. ft.	528 sq. ft.
Sprigging		
Sprigs solid—rows 12 in. apart	10 sq. ft. (1 bushel)	440 sq. ft.
Sprigs solid—rows 6 in. apart	20 sq. ft. (2 bushels)	880 sq. ft.
Broadcast and disked 3 in. deep	30 sq. ft.	1,320 sq. ft.
Broadcast verticut clippings	30 sq. ft.*	1,320 sq. ft.

*1 sq. ft. sod equals 10 sq. ft. verticut clippings.

the best selection. Many factors are to be considered in the selection of the grass but most important is whether or not the grass is suitable for the location. Some grasses may be planted by several methods; however, most of the better turf species cannot be established by seeding.

Sodding—Solid sodding of large turf areas has become quite popular since World War II. Its popularity is due to the tremendous growth of Florida along with lowered prices of sod. In many development areas and large businesses, the job is not considered complete until the turf area is complete. This involves sodding the entire area. In many area, FHA and VA loan regulations specify that the front, both sides and part of the back lot be sodded solid before a loan can be approved. This has resulted in a tremendous sod business with annual sales in excess of $20 million dollars from more than 50,000 acres of turf nurseries.

The use of sod has expanded to the point where the areas between city streets and sidewalks are solid sodded. This is specified in many contracts.

The state road department uses the solid sodding method of planting on steep slopes where erosion is likely to be a problem before seeded grasses can become established. Any of the turfgrasses may be planted by this method. The primary advantage is that the turf is practically instant and the greatest disadvantage is the cost.

Plugging or strip sodding—These are simply modifications of solid sodding in that only part of the area is covered with sod, usually in round plugs or continuous strips. Strip sodding is used on steep slopes to control erosion when solid sodding is too expensive.

Plugging is used in lawn plantings and large turf nurseries when grasses are being planted that are very slow to establish; i.e., zoysiagrasses. Plugging is not recommended for other grasses because a turf with tuffs (where the plug was placed) results. Tufts usually are scalped in subsequent mowing operations.

Sprigging—Most of the improved turf grasses are propagated by sprigging. This method requires less planting material and results in a more uniform turf. The rate of growth of the grass to be planted and money available determine how close the rows will be spaced. It is best to plant the sprigs (rhizones or stolons) end to end in the rows.

Broadcast planting—For the largest areas this modification of sprigging is best. The vegetative planting materials are spread over smaller areas within a larger one and disked in immediately. The planting material should not be disked more than 2 inches deep.

Where the turf surface must be absolutely level, as on golf courses, the planting material is broadcast and machine top dressed. The surface is left level as before planting.

Seeding—Grasses that can be propagated from seed are usually started this way. Permanent grasses suitable for turf and adapted to Florida which can be propagated by seeds are: bahia, common and U-3 bermuda, *Zoysia japonica,* centipede and carpetgrasses. Temporary grasses (for winter overseeding and ground cover) available include: bent, fescue, blue and ryegrasses. The recommended seeding rates for various requirements are shown in Table III.

In many areas, the mixing of two or more permanent grass seeds is recommended. When planting in late summer, fall or early spring, the addition of rye or fescuegrasses is recommended. For lawn purposes, most prefer a pure stand of a single grass. A single grass makes a better looking and more uniform turf.

TABLE 3.—SEEDING RATES OF VARIOUS GRASSES FOR PERMANENT AND TEMPORARY TURF IN FLORIDA

Grass	Seeding Rate Per 1000 sq. ft. pounds	Seeding Rate Per acre pounds	Minimum % purity	Minimum % germination	Approx. no. of seed/lb. 1,000's
PERMANENT TURF					
Bahiagrasses	3-6	130-260	75	80	160
Bermudagrasses	1-2	40-80	95	85	1,750
Carpetgrass	3-6	130-260	90	90	1,125
Centipedegrass	3-5 oz.	15-25	43	70	408
Zoysia japonica	1-2	40-80	Var.	Var.	1,300
TEMPORARY TURF (winter use only)					
Bentgrasses					
Golf greens only	3-6	130-260	95	90	7,000
Fescuegrasses					
Golf greens	30	1,200	95	85	600
General turf	5-10	200-400	----		
Bluegrasses					
Greens only	8-10	320-400	95	85	2,250
Ryegrasses					
Greens	40-80	1,600-3,200	98	95	275
Tees	10-20	400-800			
Fairways	10-20	400-800			
General turf	10-20	400-800	—	—	—

PREPARATION OF SEEDBED

Usually the fumigation of large areas for turf cannot be justified except for athletic fields, golf greens and tees, foundation and certified blocks. Fumigation with 1 - 2 pounds of methyl bromide per 100 square feet is recommended where the cost is not prohibitive and the use to which the turf is subjected justifies it. Fumigation will control weeds and other soil inhabiting pests and results in a better turf in a shorter period of time.

Sodding—Where solid or strip sodding, or plugging is the method of propagation, the soil should be rototilled, disked or similarly prepared. Before grass is laid, the area should have a complete fertilizer such as 6-6-6 at the rate of 20-30 pounds per 1000 square feet (860-1290 pounds per acre) incorporated into the upper 4 inches of soil.

After laying grass sod, water should be applied immediately and daily for a two-week period. Thereafter, water should be decreased and applied only as needed.

Sprigging or Broadcast Planting—The same procedure as discussed above is used here except rows are used or the sprigs are top dressed with the same soil.

Seeding—Procedure recommended for sodding applies to seeding. The seed should be spread with a cyclone or drop type seeder or a seed drill. Where seeding is accomplished with a cyclone or drop type seeder, the seed should be covered by lightly rototilling, disking or top dressing. On slopes where erosion is a factor the partial incorporation of hay or straw or the application of soil stabilizers, such as soluble plastics, burlap or similar materials is necessary.

MAINTENANCE REQUIREMENTS

After the grass becomes established, maintenance requirements such as fertilizing, watering, mowing, renovation and pest control become routine.

Fertilizing—The fertilizer requirements of large turf areas depend on the type of grass, use and appearance desired. A 1-1-1 ratio fertilizer such as 6-6-6 should be applied at the rate of 20-30 pounds per 1000 square feet in March and September. Nitrogen at the rate of one pound of N per 1000 square feet should be added to maintain the desired color. On golf greens and tees this should be every two weeks, on fairways every month and on other turf areas, at least every two months.

Watering—If irrigation is available it is best to apply at least two inches of water per watering and repeat only as needed. A little water each day is detrimental except when syringing greens at midday to maintain certain overseeded grasses.

Mowing—All turf should be mowed with a reel mower. The only exception being the bahiagrasses and then only when seedheads are a problem. Rotary mowers do more tearing than cutting and consequently leave a ragged edge. Reel mowers do a much better job of mowing turf.

Bermudagrasses require more frequent mowings than other grasses. On greens bermudagrasses should be mowed daily. On tees every other day and in other turf areas twice weekly during the growing season.

Other grasses should be mowed at least weekly. Never cut more than half of a grass blade at one mowing or in other words, never remove more than is left. Mowing reduces the root system and slows the rate of growth.

The height of cut depends on the variety of grass. The bahia and coarser St. Augustinegrasses should be mowed at 3 inches. The finer St. Augustinegrasses should be mowed at 2 - 2½ inches. Zoysia and centipedegrasses should be mowed at 1 - 1½ inches. Bermudagrasses for greens should be cut at 3/16 inch and in other places 3/4 inch.

Renovation—When turf grasses are well fertilized they form thatch. This thatch becomes so thick that the grass is difficult to mow and creates pest problems. Renovation in this sense means verticutting or thinning the grass by means of spinning verticle blades that cut through to the surface of the soil. The blades are spaced from ½ to 4 inches apart depending on the variety of grass being verticut. All grasses should be verticut once per year to maintain vigorous and healthy growth.

Pest Control—The control of weeds, insects, diseases and nematodes is involved. Information on control of turf pests in available from the Florida Agricultural Extension Service Bulletin Room, Gainesville, Florida.

One Year's Results Comparing Yield and Quality of Six Grasses Grown Alone and with White Clover in South Florida

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INTRODUCTION

Research, particularly in Central and north Florida, by many workers (1, 2, 4, 5, 6, 8, 9, 10, 11, 12, 15, 16, 19, and 20) has aided in increasing the productivity of permanent pastures and the cattle industry of Florida during the past 20 years. The increased use of pangolagrass, bahiagrasses and the improved bermudagrasses, the establishment of improved water control systems, and the continued increase in the quantities of fertilizers used have played major roles in the overall productivity of Florida pastures. Most of the work, particularly on the sandy soils of South Florida, has been limited to evaluations of a single grass species and there have been few experiments comparing the major grasses used by ranchers in the state.

This study was primarily undertaken to compare productivity and quality of six pasture grasses growing alone and in combination with Louisiana white clover on Immokalee fine sand. Although the study is a part of a three-year experiment, it is being reported separately because grass and clover-grass plots were harvested on the same dates (with one exception). Also, during this part of the experiment the grass plots were fertilized at a high rate rather than once or twice a year as during the other part. Because of these factors a good comparison can be made between the production of the various grasses and the clover-grass combinations.

EXPERIMENTAL PROCEDURE

The experimental areas consisted of two equally sized blocks. One contained the various grasses replicated three times in a randomized block design while the other was similarly designed but the grasses were grown in combination with Louisiana white clover. The grasses were pangolagrass, Coastal and Suwannee bermudagrasses, Pensacola and Argentine bahiagrasses, and carpetgrass. The plots were established in 1955-56.

Results reported herein began on May 9, 1958 and continued until April 9, 1959. During this time eight individual cuttings were made for both groups of plots.

The grass plots were fertilized with 600 pounds of 10-0-10 per acre in March, 1958. Then 500 pounds of 9-6-6 per acre was applied following each harvest, except that of October 15. The grass-clover plots were fertilized in March, July, September, and October, 1958 at the rate of 500 pounds of 0-10-20 per acre. The various dates and rates of fertilization, and harvest dates for both groups of plots are reported in Table 1.

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TABLE 1.—DATES AND RATES OF FERTILIZATION AND DATES OF HARVEST OF VARIOUS GRASSES GROWN ALONE AND IN COMBINATION WITH LOUISIANA WHITE CLOVER

Grass: Dates of fertilization	$N\text{-}P_2O_5\text{-}K_2O$ lbs./A	Grass plus clover: Dates of fertilization	$N\text{-}P_2O_5\text{-}K_2O$ lbs./A
1. March 20, 1958	60- 0-60	1. March 25, 1958	0-50-100
2. May 13, 1958	45-30-30	2. July 17, 1958	0-50-100
3. June 13, 1958	45-30-30	3. September 17, 1958	0-50-100
4. July 15, 1958	45-30-30	4. October 17, 1958	0-50-100
5. August 15, 1958	45-30-30		
6. September 17, 1958	45-30-30		
7. December 22, 1958	45-30-30		
Dates of harvests		Dates of harvests	
1. May 9, 1958		1. May 9, 1958	
2. June 12, 1958		2. June 12, 1958	
3. July 14, 1958		3. July 14, 1958	
4. August 13, 1958		4. August 13, 1958	
5. September 15, 1958		5. September 15, 1958	
6. October 15, 1958		6. October 15, 1958	
7. December 18, 1958		7. January 30, 1959	
8. April 9, 1959		8. April 9, 1959	

Plots were harvested with a conventional sickle-bar mower with an effective cutting swath of 30 inches and at a clipping height of about 2½ inches.

Representative samples of the forages were obtained in the grass-clover plots and dried at 70 to 75°C in a forced-draft oven. There was no attempt to separate the clover fraction from the swaths cut in the field. It was included as a normal constituent of the sward. The dry matter contents and dry weight yields were calculated and presented on an oven-dried basis from the fresh and dry weights of the field samples. The AOAC Method (11) was used to determine the nitrogen contents in the forage. Crude protein values were obtained by multiplying these nitrogen contents by 6.25. Statistical techniques outlined by Patterson (12) were used.

In this paper the term "nitrogen utilization" means the amount of nitrogen or protein found in the harvested forage. The percent nitrogen utilization means the number of pounds of nitrogen removed per acre by harvesting divided by the number of pounds of nitrogen per acre applied by fertilization. The result is then multiplied by 100.

RESULTS

Yields—Grasses grew well until fall and winter (Table 2). The effect of fall weather on yields was first apparent at the October 15 cutting date. At this time average yields were reduced by more than 50% from the previous month. A further reduction of growth was evident when plots were harvested on December 18. An average of only 450 pounds of dry matter per acre was produced during the approximate two months period of growth from October to December. From December until the April harvest there was also a reduction in the productivity of these grasses. For

TABLE 2.—DRY WEIGHT YIELDS IN POUNDS PER ACRE OF GRASS VARIETIES ALONE AND IN COMBINATION WITH LOUISIANA WHITE CLOVER AT DIFFERENT CLIPPING DATES IN 1958-59

Grass variety	May 9	June 12	July 14	Aug. 13	Sept. 15	Oct. 15	Dec. 18	Apr. 9	Total
1. Pensacola bahiagrass	1100	2840	1980	1130	1330	440	240	200	9260
2. Argentine bahiagrass	340	2740	2940	1610	1810	620	30	0	10090
3. Pangolagrass	1770	3210	2220	1610	1610	990	510	790	12710
4. Coastal bermudagrass	2360	2940	2150	1400	1160	580	580	890	12060
5. Suwannee bermudagrass	2970	2360	2590	1540	1610	1030	1200	950	14250
6. Carpetgrass	170	850	1300	750	1100	130	170	30	4500
Average	1460	2490	2190	1340	1440	640	450	480	
L.S.D. .05	650	740	875	205	N.S.	175	N.S.	325	2135

Grass variety + clover	May 9	June 12	July 14	Aug. 13	Sept. 15	Oct. 15	Jan. 30	Apr. 9	Total
1. Pensacola bahiagrass	970	2770	2000	1130	670	200	0	270	8010
2. Argentine bahiagrass	600	2100	2470	1730	600	130	0	30	7660
3. Pangolagrass	300	2070	1570	1300	170	70	670	930	7080
4. Coastal bermudagrass	830	2230	1430	1230	470	270	130	600	7190
5. Suwannee bermudagrass	1470	2770	1470	1530	530	300	400	830	9300
6. Carpetgrass	600	1330	1400	1370	330	100	500	1100	6730
Average	790	2210	1720	1380	460	180	280	630	
L.S.D. .05	620	340	N.S.	N.S.	170	100	N.S.	N.S.	N.S.

a period of more than three months the average production was no greater than that obtained during the two months from October to December. The total yields during the period of approximately one year indicated that the bermudagrasses and pangolagrass were superior to the bahiagrasses which in turn were superior to the carpetgrass. It was obvious that carpetgrass could not efficiently utilize the nitrogen applied because of its slow growth rate. Production by the bahiagrasses was good in the summer but very poor in the fall and winter as compared to pangolagrass and the improved bermudagrasses. For example, total production for the last three harvests in October, December, and April, showed that the bahiagrasses yielded about 700 pounds of dry matter, pangolagrass and Coastal bermudagrass about 2000 pounds, Suwannee bermudagrass 3000 pounds, and carpetgrass yielded only 300 pounds per acre.

When these grasses were grown in combination with Louisiana white clover, production results were much different than when the grasses were grown alone. It is doubtful that any real difference exists in the total yields for the period of the experiment reported here. Analyses of variance of data for three years (including the data presented here) indicated that there was no significant difference in total yields among the various grasses when combined with white clover. There were ,however, rather large yield differences when individual harvest dates are considered. Maximum production was recorded for the months of June, July, and August, with a sharp reduction in yield occuring in September. This yield reduction was about a month sooner than that occuring where heavily fertilizer grass was grown alone. Grass growth during the summer was dependent upon the quantity of nitrogen released by the clover plants and by the growth habits of the grasses. Summer production as measured by the June, July and August harvests showed that the bahiagrasses and Suwannee bermudagrass resulted in about 3 tons, pangolagrass and Coastal bermudagrass about 2½ tons. and carpetgrass 2 tons of dry matter per acre. During the winter months results were entirely different. Per acre yields of dry matter from September through the April harvests were 1140, 760, 1840, 1470, 2060, and 2030 pounds, respectively, for Pensacola bahiagrass, Argentine bahiagrass, pangolagrass, Coastal bermudagrass, Suwannee bermudagrass, and carpetgrass when grown in combination with clover. During this period bahiagrasses produced less forage than the other grasses. Carpetgrass was one of the highest yielding varieties probably because rather large early spring yields were obtained from the clover that grew more rapidly under conditions of less competition. There was a good indication that Suwannee bermudagrass was superior to the Coastal variety under the conditions of these experiments and especially during the winter months.

Dry Matter Contents.—When grasses were grown alone the bermudagrasses contained significantly higher dry matter contents than the others (Table 3). The bahiagrasses contained the next highest contents. The average dry matter contents of the grass varieties from June until October of about 26 to 28% were not significantly different. For most individual harvest dates, however, there were differences among dry matter contents of some of the various grasses. The overall average dry matter contents increased significantly in December and April. This is somewhat unusual because yields for these dates were much less than those for the others; because of the lower yields and higher protein, as will be shown later, dry matter contents would be expected to be slightly lower.

The average dry matter contents of the grass plus clover mixtures was

TABLE 3.—PERCENT DRY MATTER CONTENTS OF GRASS VARIETIES GROWN ALONE AND IN COMBINATION WITH LOUISIANA WHITE CLOVER IN 1958-59

Grass variety	May 9	June 12	July 14	Aug. 13	Sept. 15	Oct. 15	Dec. 18	Apr. 9	Average
1. Pensacola bahiagrass	32.1	27.2	28.1	27.4	27.0	25.5	32.9	36.1	29.1
2. Argentine bahiagrass	28.6	25.2	23.7	25.9	25.2	22.8	26.2		25.4
3. Pangolagrass	23.9	22.6	19.9	20.6	21.6	18.7	22.6	29.9	22.5
4. Coastal bermudagrass	38.1	36.6	35.6	33.5	27.3	30.8	36.3	39.7	34.7
5. Suwannee bermudagrass	38.3	33.5	33.1	29.3	31.0	28.4	36.5	39.0	33.6
6. Carpetgrass	28.4	24.8	25.4	24.7	25.3	24.4	25.8	29.2	26.0
Average	31.3	28.3	27.4	26.9	26.2	25.1	30.1	34.8	28.6
L.S.D. .05	4.1	3.9	2.2	4.1	N.S.	2.9	6.6	5.2	2.7

Grass variety + clover	May 9	June 12	July 14	Aug. 13	Sept. 15	Oct. 15	Jan. 30	Apr. 9	Average
1. Pensacola bahiagrass	32.1	27.2	28.1	21.1	28.0	29.1		29.2	27.8
2. Argentine bahiagrass	31.6	28.1	26.6	30.4	27.1	26.3		27.9	28.3
3. Pangolagrass	29.5	21.8	22.5	20.1	24.5	23.1	26.5	23.8	24.0
4. Coastal bermudagrass	34.7	40.7	39.6	28.0	31.7	31.1	30.1	27.9	33.0
5. Suwannee bermudagrass	31.6	33.7	35.7	31.6	31.2	30.7	26.1	27.6	31.0
6. Carpetgrass	28.3	24.0	24.7	25.8	28.4	26.9	22.9	25.7	25.8
Average	31.3	29.3	29.5	26.2	28.5	27.9	26.4	27.0	28.3
L.S.D. .05	N.S.	3.4	2.4	7.9	2.3	3.2	...	N.S.	

nearly the same as that of the grasses grown alone. The bermudagrasses plus clover contained the largest dry matter contents followed next by the contents of the bahiagrasses.

Protein Contents—The crude protein contents are shown in Table 4. The average contents for grasses grown alone showed that the bahiagrasses and the carpetgrass were higher than the others. Protein contents between May and September averaged between 7.9 and 9.5, and increased markedly in the October and December cuttings when the yields were reduced tremendously because of cold weather.

In clover combinations the overall average protein content was 12.8%. This was about 3% higher than the average for the grasses grown alone. The carpetgrass-clover mixture had the highest average protein content which ranged from a low of 8.4% in September to 20.3% in April, and the protein content increased as the proportion of clover to grass increased.

Nitrogen Utilization—Pensacola bahiagrass, Argentine bahiagrass, pangolagrass, Coastal bermudagrass, Suwannee bermudagrass, and carpetgrass contained 842, 903, 1051, 1063, 1265, and 432 pounds of crude protein per acre, respectively, during the one year period of this test. The per cent nitrogen utilization of the 330 pounds applied per acre varied from 21% by carpetgrass to 61% by Suwannee bermudagrass. The bahiagrasses utilized about 42% and the pangolagrass and Coastal bermudagrasses utilized about 51% of the nitrogen applied. Since some of the 330 pounds of nitrogen remained in the roots after the last harvest these percentage values are lower than those that would be obtained if further clippings were made without additional nitrogen fertilization. Evidence of this was obtained by comparing the pounds of nitrogen removed through clipping from one harvest to the next. The July harvest resulted in an average nitrogen removal of about 30 pounds per acre or about 67 per cent of the 45 pounds of nitrogen applied immediately after the June harvest. These average values remained relatively high until October 15 when only about 14 pounds of nitrogen was removed at harvest. In December and April the removal of nitrogen also was limited. The largest quantity of nitrogen removed for any single period between harvests was by Argentine bahiagrass which absorbed about 38 pounds per acre during the June 12 to July 14 period. Highest removal for other grasses was: Pensacola bahiagrass—33, pangolagrass—34, Coastal bermudagrass—36, Suwannee bermudagrass—37, and carpetgrass—16 pounds of nitrogen per acre. These values represent a per cent utilization of the 45 pounds of nitrogen applied per acre of 84, 73, 75, 80, 82 and 36, respectively.

The quantities of protein removed by the clippings of mixtures of the grasses and clover were 810, 778, 819, 864, 1087, and 909 pounds of crude protein per acre for Pensacola bahiagrass, Argentine bahiagrass, pangolagrass, Coastal bermudagrass, Suwannee bermudagrass and carpetgrass, respectively. There was very little difference between varieties. However, when values for the grasses plus clovers are compared to those for grasses alone there are considerable differences. For example, carpetgrass contained only 432 pounds of protein in the tops when fertilized with nitrogen, but the combination of carpetgrass and clover with no nitrogen fertilization removed more than twice that much. The other grasses plus clover removed less nitrogen than did the respective grasses grown alone and fertilized with nitrogen.

TABLE 4.—PERCENT CRUDE PROTEIN CONTENTS OF VARIOUS GRASSES GROWN ALONE AND IN COMBINATION WITH LOUISIANA WHITE CLOVER IN 1958-59

Grass variety	May 9	June 12	July 14	Aug. 13	Sept. 15	Oct. 15	Dec. 18	Apr. 9	Average
1. Pensacola bahiagrass	10.4	7.3	8.7	9.4	9.1	14.7	13.0	12.7	10.7
2. Argentine bahiagrass	12.2	7.9	8.0	9.1	9.3	13.1	12.2		10.3
3. Pangolagrass	6.9	6.6	9.0	9.5	8.9	12.0	11.3	5.7	8.7
4. Coastal bermudagrass	8.1	7.6	8.8	10.4	8.5	12.8	11.4	8.2	9.5
5. Suwannee bermudagrass	7.4	7.2	8.9	9.7	9.1	15.0	11.6	6.5	9.4
6. Carpetgrass	11.1	10.7	7.6	9.1	9.2	13.5	13.2	10.9	10.7
Average	9.4	7.9	8.5	9.5	9.0	13.5	12.1	8.8	9.9
L.S.D. .05	0.9	1.2	N.S.	N.S.	N.S.	N.S.	N.S.	0.8	0.9

Grass variety + clover	May 9	June 12	July 14	Aug. 13	Sept. 15	Oct. 15	Jan. 30	Apr. 9	Average
1. Pensacola bahiagrass	15.7	8.7	8.9	9.3	7.5	9.7		21.2	11.6
2. Argentine bahiagrass	16.7	10.8	8.5	9.1	7.5	10.9		22.0	12.2
3. Pangolagrass	20.0	10.5	8.4	8.7	8.6	10.2	18.9	17.9	12.9
4. Coastal bermudagrass	17.2	10.7	9.6	9.0	9.5	10.9	17.3	20.8	13.1
5. Suwannee bermudagrass	15.8	8.7	7.6	10.0	9.4	9.8	18.7	18.0	12.3
6. Carpetgrass	21.3	12.6	8.4	8.8	7.8	9.7	25.1	21.8	14.5
Average	17.8	10.3	8.6	9.2	8.4	10.2	20.1	20.3	12.8
L.S.D. .05	2.3	N.S.	N.S.	N.S.	N.S.	N.S.		3.0	

DISCUSSION

Only one-year's results are reported and yield variations would be expected from year to year because of environmental factors. The average maximum and minimum temperatures were not believed sufficiently different from those of the last 10 years, however, to indicate that the comparisons among varieties would change markedly.

The experimental procedure would more closely resemble a commercial green-chop than a grazing program. The amount of forage obtained by clipping may be different from that eaten by cattle. However, the difference was minimized as plots were harvested frequently. This prevented the grasses from building up an excess of stemy, unpalatible material that would have been included in the results by clipping but would not have been consumed by the cattle because of their preferentially grazing the more tender portions of the grass. It is believed yields and quality approximated what grazing cattle would have obtained.

None of these grasses provided sufficient forage in the winter to maintain the number of animals that could be maintained in the summer, and none are good winter grasses. This makes it imperative to provide additional winter feed. Clovers usually are helpful in the early spring but deferred grazing or additional winter feed is necessary if the stocking rate is based on the pasture available in the summer months.

SUMMARY

Six grasses grown on Immokalee fine sand alone and in combination with white clover were compared.

1. The bahiagrasses and particularly carpetgrass grown alone were inferior to the bermudagrasses and pangolagrass primarily because of the poorer winter and early spring growth. Total yields were the same when these grasses were grown with clover.
2. Protein contents of the bahiagrasses and carpetgrass grown alone generally were higher than those for the other grasses.
3. Pangolagrass and the bermudagrasses were better able to utilize the high rate of 330 pounds of nitrogen per acre that was applied during the year.
4. All varieties except carpetgrass yielded more forage per acre when grown alone with applied nitrogen than when grown with clover and without applied nitrogen.

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Another Look At Tall Fescue For Northwest Florida

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One of the great needs of the cattleman is to be able to graze cattle throughout the year. Research has continually been carried on to attain this end. Summer perennial grasses in conjunction with winter-grazed small grains have been the forages which have brought this dream close to reality. Concurrently, the search has gone on for a perennial grass which would provide winter grazing. Perhaps tall fescue comes closer to being an answer to the problem than past results have indicated.

Reported results with fescue have often been contradictory and inconclusive. The grass has been discussed pro and con since it was introduced into the Southeast. Of the tall fescues, Kentucky 31 has probably aroused the most interest in this area. Introduced into the Perdido River Soil Conservation District by Soil Conservationists in the early forties, Kentucky 31 fescue failed to give the miraculous performance expected of it, but later use by farmers of the district has proved more successful (10).

Early experimental work with Kentucky 31 fescue at the West Florida Station was done in combination with such legumes as crimson clover, trefoil, Kobe lespedeza, and ladino and red clovers. In unpublished data, combined season yields were found to be higher in combination with crimson clover and lowest with trefoil. Survival ability was observed in the early work to be rather low on light sandy soil. Langford and Hutton

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(5) obtained beef gains of 309 pounds per acre when tall fescue and clover were grazed from October 10, 1952 until April 27, 1953. The same workers found that tall fescue stands were reduced by legumes with close and frequent clipping favoring the legumes. Stokes and Killinger (8) found that Kentucky 31 produced most growth when planted in mid-October to mid-November with September and December seedings not quite so vigorous. They found also that growth of fescue was stimulated by 1-2 tons of limestone and 400 to 600 pounds per acre of 6-6-6. In the absence of limestone, they observed that fescue failed to make satisfactory growth on acid flatwoods soil. Hodges, Jones, and Kirk (6) found that fescue at Ona, Florida when planted in November did not make a vigorous growth and was crowded out by other grasses. Thompson (9) found that spring plantings of fescue failed because of competition from weeds.

Bair and Kidder (1) observed that Kentucky 31 fescue exhibited little or no damage from seven hours below freezing with minimum temperatures of 27° F. on the peat and muck soils of the Everglades in January of 1949. They also found that Kentucky 31 demonstrated more disease resistance than Alta during the third winter after planting.

Davis and McCall (4) observed that nitrate levels in various forages may approach toxic levels when management practices have not taken into account weather conditions and their relation to the time of harvest. They emphasized that this was particularly true of *Festuca elatior*.

Work done in Louisiana by Carpenter and Brown (3) produced results in which it appeared that steers grazing fescue and clover pastures made a higher daily gain when they were fed a concentrate supplement. On these pastures, which contained 40% fescue and 60% S-1 white clover, the feeding of the concentrate supplement of corn and cob meal plus cottonseed meal was not profitable. They further observed that fescue and clover furnished a longer grazing period than either ryegrass or wheat pastures.

METHODS AND MATERIAL

Three paddocks of 1.25 acres each were seeded to Kentucky 31 fescue in the fall of 1957. These paddocks were on soils of the Norfolk, Tifton, and Red Bay series. This area had been in other pasture experiments since 1950 and there was a considerable P_2O_5 and K_2O residual present at this time. Approximately 500 pounds per acre of 4-12-12 were disked into the seedbed at the time of planting. A previous application of dolomitic limestone had been applied at the rate of 2.5 tons per acre. The seeding was made with a cultipacker at a rate of 10 to 12 pounds per acre. Fertilization in 1958 consisted of 500 pounds of 0-14-14 and 200 pounds of ammonium nitrate per acre on August 15 and an additional application of 200 pounds of ammonium nitrate per acre in October, 1958 and January, 1959. Fertilization during the 1959-60 season consisted of 500 pounds of 0-14-14 and 200 pounds of ammonium nitrate per acre in mid-September with additional applications of 200 pounds of ammonium nitrate per acre in November and January and a fourth application on one paddock in April. The program of fertilization in 1960-61 consisted of 500 pounds of 0-14-14 and 200 pounds of ammonium nitrate per acre in mid-August with the same rate of ammonium nitrate again in November and January.

These three paddocks were grazed only to control weeds during the

spring of 1958. Grazing periods are given in Tables 1 and 2. All grazing was rotational and removal was generally accomplished when the grass had been grazed to the four-inch level. Cattle used in these trials were yearling stocker steers of Angus and Hereford breeding.

Fifteen paddocks of 1.1 acres each were seeded to Kentucky 31 fescue in early November, 1959. These are on Tifton and Red Bay soils. One ton per acre of dolomite was applied in October. Seeding was made with a cultipacker-seeder at a rate of 10 to 12 pounds per acre. At the time of seeding, O-14-14 was disked into the seedbed at a rate of 500 pounds per acre. Ammonium nitrate was applied at 100 pounds per acre in February and again in April and June. In late August of 1960, applications of 500 pounds of 0-14-14 and 200 pounds of ammonium nitrate per acre were made. Additional applications of ammonium nitrate were made at the same rate in November and January.

A minimum of grazing to control weeds was allowed in the spring of 1960. The paddocks were divided into five groups of three blocks each for rotational grazing. Table 3 shows the various treatments and grazing periods. Yearling stocker cattle were used for these trials. All cattle were

TABLE 1.—TALL FESCUE GRAZING TRIALS AT THE WEST FLORIDA EXPERIMENT STATION

1958-59

	Dates grazed					
	Sept. 17-Dec. 3	Dec. 3-Jan. 16	Jan. 16-Feb. 16	Feb. 17-March 24	March 24-May 6	Sept. 17-May 6
Days grazed	77	44	Off	35	43	199
Animals/acre	1.33	1.33	Off	1.33	2.58	1.60
Cow days/acre	102	58	Off	47	111	318
Total gain/acre	247	67	Off	52	107	473
Gain/cow day	2.42	1.16	Off	1.11	0.96	1.49
Total gain/animal	177	50	Off*	39	42	308
Daily gain	2.30	1.14	Off	1.11	0.98	1.55

Remarks

Initial weight of animals was 491 lbs.
Final weight of animals was 800 lbs.
1.6 animals/acre from Sept. 17-Oct. 3
Animals were on oats Jan. 16-Feb. 17

1959-60

	Dates grazed					
	Sept. 28-Dec. 11	Dec. 12-Feb. 4	Feb. 5-Mar. 7	Mar. 8-Apr. 20	Apr. 21-May 10	Total
Days grazed	74	55	31	44	20	224
Animals/acre	1.06	1.06	1.06	*	1.60	1.16
Cow days/acre	78.44	58.30	32.86	58.37	32.00	259.97
Total gain/acre	33.12	56.97	76.85	52.00	38.66	257.60
Gain/cow day	0.42	0.98	2.34	0.89	3.75	0.99
Total gain/animal	31.25	53.75	72.50	32.50	24.16	214.16
Daily gain	0.42	0.98	2.34	0.73	1.21	0.96

*1.06 animals per acre for 22 days and 1.60 animals per acre for 22 days.

TABLE 2.—THIRD-YEAR KY. 31 FESCUE GRAZED BY STOCKERS AT THE WEST FLORIDA EXPERIMENT STATION.

1960-61

Animal data	Sept. 20 Oct. 20	Oct. 21 Nov. 18	Nov. 19 Dec. 16	Dec. 17 Jan. 13	Jan. 14 Feb. 3	Feb. 20 Mar. 28	Mar. 29 Apr. 27	Apr. 28 May 15	May 16 June 5	Totals
Days grazed	30	28	28	28	21	37	30	18	21	241
Animals/acre	1.07	1.07	1.07	1.07	1.07	1.07	2.67	2.67	1.60	1.43
Gain/steer/day	0	0.80	0.80	1.43	0.71	0.84	0.80	−0.03	1.10	0.70
Gain/acre/day	0	0.86	0.86	1.53	0.76	0.90	2.14	−0.08	1.76	1.00
									Total gain/acre	241

TABLE 3.—FIRST-YEAR KY. 31 FESCUE GRAZED BY STOCKERS AT THE WEST FLORIDA EXPERIMENT STATION.

Group		Sept. 20 Oct. 20	Oct. 21 Nov. 15	Nov. 19 Dec. 16	Dec. 17 Jan. 2	Feb. 27 Mar. 31	Mar. 31 Apr. 27	Apr. 27 May 15	Totals
1	Day Grazed	30	28	28	16	32	27	18	179
	Animals/acre	1.21	1.21	1.21	1.21	1.4	2.42	2.42	1.55
	Gain/steer/day*	2.1	1.13	1.87	2.05	2.5	2.03	0.1	1.68
	Gain/acre/day*	2.54	1.37	2.26	2.48	3.5	4.9	0.25	2.61
								Total gain/acre	467.19
2	Days grazed	30	28	28	16	32	27	18	179
	Animals/acre	1.21	1.21	1.21	1.21	1.4	2.42	2.42	1.55
	Gain/steer/day*	0.53	0.87	1.30	1.06	2.14	1.8	0.39	1.24
	Gain/acre/day*	0.64	1.05	1.57	1.28	3.0	4.4	0.92	1.92
								Total gain/acre	343.68
3	Days grazed	30	28	28	16	32	27	18	179
	Animals/acre	1.81	1.81	1.81	1.81	1.76	2.42	2.42	1.95
	Gain/steer/day	2.17	1.17	2.34	1.74	2.0	3.3	−0.07	1.92
	Gain/acre/day*	3.93	2.12	4.24	3.15	3.5	8.0	−0.17	3.75
								Total gain/acre	671.25
4	Days grazed	30	28	28	16	32	27	18	179
	Animals/acre	1.21	1.21	1.21	1.21	1.4	2.42	2.42	1.55
	Gain/steer/day*	1.03	0.91	1.13	1.59	2.2	1.8	0.04	1.28
	Gain/acre/day*	1.25	1.10	1.37	1.92	3.1	4.4	0.08	1.99
								Total gain/acre	356.21
5	Days grazed	0	28	28	16	32	27	18	149
	Animals/acre	0	1.21	1.21	1.21	1.4	2.42	2.42	1.62
	Gain/steer/day*	0	1.04	0.96	0.08	3.2	1.9	0.6	1.49
	Gain/acre/day*	0	1.26	1.16	0.10	4.5	4.5	1.43	2.42
								Total gain/acre	360.58

*Pounds

Groups 1 and 3 received daily supplements of five pounds of ground snapped corn per animal.

Groups 2, 4, and 5 were grazed only.

off the pastures from January 2 until February 27 because of cold weather which prevented forage production during this time.

Three paddocks of 2.29 acres each were established in November, 1959 on Eustis fine sand. Dolomitic limestone was applied at one ton per acre, 18% superphosphate at 500 pounds per acre and ammoniated superphosphate at 125 pounds per acre. Seeding and subsequent fertilizer applications were approximately the same as those previously given for the 1.1 acre paddocks. Weed control in the spring of 1960 was accomplished by mowing. These paddocks were used in a study utilizing brood cows. Grazing data are given in Table 4.

In order to determine the effect of grazing tall fescue late in the spring, a clipping trial was set up in the fall of 1959. This trial was located on Kentucky 31 fescue which had been established in October, 1957. Establishment and maintenance, with regard to fertilizer treatments, have been approximately the same as those given for the 1.25 acre paddocks. The experiment is located on Carnegie fine sandy loam and is replicated three times using 12 by 29 foot plots. Data are given for one year in Table 5.

A fertility trial was established in the fall of 1959 using nine replications of 8 by 8 foot plots. These are located on Carnegie fine sandy loam and establishment followed the same procedure as previously outlined for the 1.1 acre paddocks. In September, 1960 the main plots received

TABLE 4.—FIRST YEAR KY. 31 FESCUE GRAZED BY BROOD HERD AT THE WEST FLORIDA EXPERIMENT STATION.

1960-61

	Nov. 10 Dec. 28	Feb. 23 Apr. 13	Apr. 14 May 19	Totals	On small grain Dec. 29-Feb. 23
Days grazed	48	49	36	133	56
Cows/acre	0.87	0.87	0.87	0.87	
Calves/acre	0.87	0.87	0.87	0.87	
Gain/cow/day	1.34	2.47	0.25	1.46	−1.82
Gain/calf/day	1.88	2.21	1.57	1.92	1.43
Gain/cow/acre/day	1.17	2.15	0.22	1.27	−1.58
Gain/calf/acre/day	1.64	1.92	1.37	1.67	1.24
Total gain/acre/day	2.81	4.07	1.59	2.94	−0.34
			Total gain/acre	391.02	

TABLE 5.—YIELD IN POUNDS OF DRY MATTER PER ACRE OF KY. 31 FESCUE AT VARIOUS CLIPPING HEIGHTS AND DATES FOLLOWING CLIPPING TREATMENTS IN THE SPRING, 1960.

Date of last clipping in spring, 1960	Clipping height	Average of 3 replications November '60	March '61	Total
May 12	1½″	1894	3767	5661
	4½″	2744	3221	5965
June 9	1½″	2564	2841	5405
	4½″	2093	2941	5034
Not clipped	1½″	2330	3799	6129
	4½″	2415	2442	4857

500, 1000, and 1500 pounds per acre of 0-14-14, respectively, with these split into subplots receiving 200, 400, 600, and 800 pounds per acre of ammonium nitrate. Identical applications of ammonium nitrate were made in November, 1960 and February, 1961. Plots were clipped to a height of 4½ inches on November 14, 1960 and on March 24, 1961. Data are presented in Table 6.

RESULTS AND DISCUSSION

Jeffers (7) initiated the work covered by this paper and obtained the first year's data. Following the rather good gains and long periods of grazing obtained in that first year, he envisioned that possibly the cool season perennials might provide a greater share of the grazing from a yearly grazing program than the more outstanding warm season perennials. During the first year, 199 grazing days were obtained, with 224 days on the following year and 241 during the 1960-61 season. Grazing periods of 179 days and 133 days were obtained during the first year on paddocks established in 1959 as shown in Tables 3 and 4. The latter figure represents data for brood cows on Eustis fine sand while the former is for stocker cattle in Tifton and Red Bay soils. A later beginning date for the brood cows is responsible for the shorter grazing period.

Gains made during the first year of the study were better than those of subsequent years as observed on paddocks grazed more than one season. A means must be found to overcome this situation. Inspection of the data will indicate that first-year gains were similar for all groups of paddocks grazed by stockers in 1960-61 except where a supplemental feed was given to the cattle. Comparison of the data obtained on the first-year paddocks in 1958-59 and that obtained on first-year paddocks in 1960-61, Tables 1 and 3, will show that for cattle receiving only forage, the former were somewhat higher in so far as total gain per acre is concerned. A more comparable gain was obtained by one group of steers in which an average of 1.55 animals was carried per acre and a daily supplement of five pounds of ground snapped corn was fed per steer. The same supplement given to another group in which the average carrying capacity was 1.95 animals per acre resulted in a greatly increased gain, Table 3. It is along the line of determining efficient stocking and feeding rates that further study will be directed. However, efficient fertilization must not be overlooked.

Removal of cattle from the fescue paddocks in early May of 1960 allowed the grass to produce a seed crop which averaged 200 pounds per

TABLE 6.—TOTAL YIELD OF TWO CUTTINGS OF KY. 31 FESCUE IN POUNDS OF DRY FORAGE PER ACRE AT VARIOUS RATES OF NPK
(Average of Nine Replications)

WEST FLORIDA EXPERIMENT STATION

Lbs. N	70 Lbs. each of P_2O_5 and K_2O	140 Lbs. each of P_2O_5 and K_2O	210 Lbs each of P_2O_5 and K_2O
200	4102	3993	4828
400	5627	5735	6661
600	5046	5826	6171
800	5118	5499	6316

acre. This might not be considered a large seed yield when compared with some of those obtained in other states; however, when added to the beef yields attainable, it could increase the profit considerably. Buckner (2) who has worked extensively with fescue observed that clipping treatments greatly affected seed yields on fertilized plots but did not do so on unfertilized plots. Fertility would be considered to be rather high on the pastures involved in this study and rather heavy grazing in the spring of 1961, followed by drouth after the grazing was terminated, resulted in complete failure of a seed crop. This places an increased emphasis on the necessity for good management practices when using fescue. The use of heavy nitrogen fertilization makes an expensive maintenance program. Forage must be used with great efficiency if a profit is to be made. Economy of the wintering program may dictate a lowering of the nitrogen rates. However, there are indications that this cannot be done if sufficient forage is to be produced during the winter months. One method of fescue management is to use fescue in conjunction with small grains and make both produce more profit per acre by obtaining maximum for each. With six to seven months grazing from fescue plus one to two months on the small grains, it appears that fescue can be efficiently utilized and also a small grain crop obtained.

Preliminary clipping data designed to determine the effects of termination of clipping on various dates has not yet progressed to the point of producing conclusive evidence. Inspection of the data in Table 5 would indicate that, for the one year, the later clipping may have reduced yields somewhat in the following fall and winter but inflicted no serious stand damage. This phase of the overall investigation of fescue needs further study.

Kentucky 31 fescue was fertilized annually at rates of 70, 140, and 210 pounds each of P_2O_5 and K_2O on main plots and at 200, 400, 600 and 800 pound rates of N on subplots (Table 6). This study, in which nitrogen was applied in three equal applications, gave indications that the highest average forage yield was obtained at the 400 pound level of N in the 210 pound level of P_2O_5 and K_2O. This level of N appeared to be the most productive level of N at each level of P_2O_5 and K_2O except for a slight advantage shown at the 600 pound level of N in the 140 pound level of P_2O_5 and K_2O. It was noted that some damage was done to the grass by the two higher levels of N with a considerable amount of yellowing for a few days following application. In contrast, however, these plots maintained dark green color during periods in the winter when the grass at the 200 pound level presented a yellow appearance due to cold dry weather.

The use of fescue as pasture for brood cows may be considered to be a somewhat dubious practice especially in view of the high nitrogen requirements of the grass. Brood cows with or without calves should be wintered as inexpensively as possible. However, a number of factors should be considered in determining the real efficiency of wintering a brood cow. This subject does not properly fall under the scope of this study of fescue except that it is one avenue of investigation and data in Table 4 show that stocker calf production, by wintering cows on fescue, may be a possibility.

SUMMARY

Data are presented to show that tall fescue can be grazed over a rather long period in the Northwestern part of Florida with good gains on both

stocker cattle and unweaned calves. The use of supplementary feeding is shown to be advantageous. A discussion of the need for good management in relation to feeding and stocking is given. Seed production is considered as a possible means of increasing profit from fescue. Indications are given of the need to use high levels of nitrogen and to terminate grazing in the early part of May.

These preliminary findings are presented in an effort to stimulate greater interest in research with fescue. Many answers have not yet been found, but a grass which can provide grazing from September until May must be thoroughly investigated before it is written off as a failure.

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The Role of Growth Inhibitors in Reducing Winter Injury in Florida's Pastures[1]

O. CHARLES RUELKE[2]

A critical shortage of high quality fresh green forage develops during most winters in Florida, despite the favorable climate which prevails most of the time during the winter. To alleviate the forage shortage, farmers and ranchers use hay to carry the cattle through this period. Excessive humidity and high summer rainfall make it impractical to cure and store quality hay during periods in the summer when there is a surplus of grass. Research has shown that fertilizing for hay production in the fall, when it would cure out and keep, was practical (5). When heavy rates of nitrogen were applied to grasses, serious reductions in stands and early spring grazing occurred due to repeated frosts which killed the regrowth during the winter (6).

Various growth regulating materials used to induce winter dormancy and reduce winter injury have been tried with citrus in Florida (2).

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[3]The author wishes to express appreciation to the Naugatuck Chemical Division of the United States Rubber Company, Naugatuck, Connecticut, for supplying the maleic hydrazide (MH 30).

Cooper (3) reported that when maleic hydrazide and 2,4,5-T were applied to normal citrus trees, there was a slight inhibition of cambial activity, pronounced bud inhibition, and 1°F. increase in cold hardiness. Cooper (3) wrote that Stewart (9) obtained effective bud inhibition from maleic hydrazide treatments of cold injured trees in Florida when sprays were applied to dormant defoliated trees. Samygin (8) reported that spray applications of maleic hydrazide on three year old lemon seedlings arrested growth but frost resistance was negligible, not exceeding 1°C.

Preliminary investigations (7), in Florida, have shown that winter injury of pangolagrass was reduced by a fall spray application of maleic hydrazide.

This research has been carried out to study the effects of the application of various rates of the growth inhibitor, maleic hydrazide (MH-30)[3], after the hay has been harvested from plots of various perennial grasses which have had different rates of nitrogen applied for production of hay in the fall.

MATERIALS AND METHODS

Replicated plots of established Coastal bermudagrass, Pensacola bahiagrass and pangolagrass, which had received 375 pounds of 8-8-8 fertilizer on March 31, 1960, were kept mowed and cleared off during the summer. The last mowing during the summer occurred on August 16, 1960. On August 18, 1960, ammonium nitrate fertilizer was applied at the rates of 50, 100, and 200 pounds per acre of elemental nitrogen. On October 19, 1960, forage yields were ascertained.

Following removal of the fall hay crop on November 7, 1960, the regrowth was sprayed with the growth inhibitor, maleic hydrazide (MH-30) at the rates of 0, 2, 6, and 18 pounds per acre of active ingredients. Visual estimates of the percentage of area covered by dead plants were made on March 27, 1961. First cutting forage yields were obtained on June 23, 1961 on a dry weight basis.

RESULTS AND DISCUSSION

In a preliminary experiment (7) it was found that when maleic hydrazide was sprayed on fertilized pangolagrass (prior to harvest for hay) at the rates of 0, 2, 6, and 18 pounds per acre there was inhibited subsequent growth during the winter. Higher rates of maleic hydrazide applied to the grass had a burning effect on the grass and reduced the yield of the hay harvested in the fall. However, there was less winter injury in plots receiving 6 and 18 pounds of maleic hydrazide per acre and there were significantly greater yields of forages in the first cutting the following year.

In addition, when maleic hydrazide was applied to pangolagrass prior to harvest for hay, there was a significant decrease in the percentage of crude protein in the hay as higher rates of maleic hydrazide were applied, and there appeared to be a corresponding increase in percentage of total available carbohydrates. Birch and Vickery (1) reported that maleic hydrazide, applied at topping time, increased the total sugars and reducing sugar content throughout the flue-cured tobacco plant.

With this information, it seems more advisable to apply the growth retardant to the regrowth after the fall hay crop has been harvested and prior to the first frost of the winter.

TABLE 1.—Effect of Various Rates of Nitrogen and Maleic Hydrazide on Dry Forage Yield in the Fall, Percentage of Dead Plants in the Following Spring, and Dry Forage Yields the Following Spring in Various Grasses.

Grass	Nitrogen Lbs./A Applied 8/18/60	Dry Forage Lbs./A 10/19/60	Maleic Hydrazide Lbs./A 11/7/60	Dead plants est. % 3/27/61	Dry Forage Lbs./A 6/23/61
Coastal bermudagrass	50	3620	0	5	580
			2	15	600
			6	5	840
			18	65	560
	100	4040	0	10	870
			2	3	1110
			6	6	1420
			18	88	640
	200	4590	0	4	1550
			2	2	2000
			6	12	2380
			18	94	920
Pangolagrass	50	3760	0	23	360
			2	17	340
			6	17	470
			18	22	410
	100	4270	0	25	310
			2	13	260
			6	17	370
			18	43	450
	200	4810	0	50	210
			2	70	330
			6	62	270
			18	57	340
Pensacola bahiagrass	50	1400	0	2	610
			2	2	730
			6	5	540
			18	57	450
	100	2220	0	0	1020
			2	1	1120
			6	8	1120
			18	75	930
	200	3180	0	0	1640
			2	2	1610
			6	8	1340
			18	85	1090

The effect of various rates of nitrogen fertilizer and the growth inhibitor (maleic hydrazide) applied in the fall, on the fall yield, percentage of dead plants observed in the following spring, and the forage yield the following spring in various species of grasses are shown in Table 1.

These data show increases in yield of forage following the fall application of nitrogen. The growth inhibitor sprayed at the rates of 2 and 6 pounds per acre on the regrowth of the grasses, after harvest of hay in the fall, reduced the percentage of winter killed plants in many cases, and usually there were higher yields of forage the first cutting the following year because there were more living plants present. First cutting yields of Coastal bermudagrass the following year were noticeably greater, es-

pecially in the plots which received 100 and 200 pounds of nitrogen. Yields of plots which received 18 pounds of maleic hydrazide were lower than the check plots in bermudagrass because the high rates of maleic hydrazide injured the plants prior to winter and reduced stands. Likewise, Cooper (3) reported that severe injury to citrus resulted from concentrations of maleic hydrazide which were effective enough to inhibit growth.

All of the first cutting yields of pangolagrass the following year were low because of the consistently cold winter. In general, it appeared that the growth inhibitor was less effective in preventing winter injury in pangolagrass when temperatures were consistently cold during the winter, than when there were prolonged warm periods followed by repeated frosts, as occurred the previous winter.

Pensacola bahiagrass is more cold resistant than pangolagrass under similar treatments (4). In the experiment reported here no appreciable advantage was gained by the use of maleic hydrazide on bahiagrass. Eighteen pounds per acre severely injured the plants prior to winter and reduced the stands and yields of the first cutting the following spring.

SUMMARY AND CONCLUSIONS

Studies of perennial grasses fertilized in the fall with 50, 100, and 200 pounds per acre of nitrogen to produce hay for winter have been expanded. The growth inhibitor, maleic hydrazide, was sprayed on the regrowth of grasses, at the rates of 0, 2, 6, and 18 pounds per acre after the harvest of hay in the fall.

All of the grasses responded to the application of nitrogen in the fall.

Percentage of winter killed plants of Coastal bermudagrass was reduced in most cases, and first cutting yields the next year were greater when 2 and 6 pounds of maleic hydrazide were applied to the regrowth after the hay was harvested. Eighteen pounds per acre of maleic hydrabide injured the plants, reduced the stands, and reduced the yield the following spring.

In general, it appeared that the growth retardant maleic hydrazide was more effective in preventing winter injury of the more frost sensitive grasses during winters when there were prolonged warm periods followed by repeated frosts, than when temperatures were consistently cold through out the winter.

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Influence of Row Direction On Microclimate, Yield, and Damage by Freezing in Lupine and Oats[1]

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Lupine and oats are grown in Florida in the season when the sun is declined southwardly and the angle of incidence of the sun's rays to the earth's surface is less than 50 degrees. Consequently, solid rows of these upright crops oriented in a east-west direction cast shadows on the north side of the row. If the plants are as tall as or taller than the width of the row, direct rays from the sun may not reach the soil surface during most of the day. Because of the continuous shade, soil and air temperatures are expected to be lower and humidity higher in rows oriented east-west. Therefore, reduced plant growth and higher incidence of disease may result. Rows oriented north-south will receive a more even distribution of sunlight on both sides and on the soil between the rows.

Dungan *et al.* (1) demonstrated that corn planted in rows 2 feet apart yielded significantly more forage and grain when planted in a north-south direction rather than an east-west. However, Pendleton and Dungan (4, 5) were able to show an increase in yield of oats in favor of north-south rows only four of seven years of testing. The advantage was greater when rows were more than 8 inches apart. Orientation of rows was found by Eno and Westgate (2) to be important in celery production during the winter in Florida. Yield was increased over 20% and plant height was slightly greater in north-south rows. Disease problems were also reduced by the north-south orientation.

The preliminary experiments reported here were designed to survey effect of row direction on microclimate and yields of lupine and oats. Observations on freeze damage as a result of clipping management in the row-direction tests are also included.

EXPERIMENTAL PROCEDURE

Lupine (Var. Borre) was planted at the rate of 100 pounds per acre in rows 11 inches apart. Six replications of plots 16 rows wide and 15 feet long were oriented east-west and north-south. Lupine was planted November 3, 1958 on Arredondo fine sand after 500 pounds of 8-8-8 fertilizer had been broadcast uniformly. When the lupine was 4 to 5 inches high, thermocouples were installed at 1-inch soil depths 3½ and 7 inches from the north side of east-west rows and the west side of north-south rows. Air temperatures and dew points were measured at 3 and 12 inches above ground and 3 inches from rows oriented both north-south and east-west. Visual surveys were made regularly to determine occurrence of any disease. Dry-weight yield of tops cut at 2-inch stubble height was

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[3]Nitrification study by C. F. Eno, Soils Department, University of Florida. (Unpublished Data.)

measured January 26 on 5 x 10 foot areas of all plots and February 18 on other 5 x 10 foot areas of the same plots.

The lupine experiment was repeated with similar procedures the following year with a bitter blue variety. Plot size was changed to 8.7 x 17.5 foot and the number of replications was increased to seven. Only one harvest was made in the second-year test.

"Florad" oats were planted November 18, 1959 in rows 10 inches apart and oriented north-south and east-west. The soil was fertilized uniformly with 400 pounds of 8-8-8. Oats were seeded at the rate of 4 bushels per acre in 25 x 25 foot plots replicated 4 times. After the oats were 6 to 8 inches tall, 100 pounds per acre of N as ammonium sulfate was applied as topdressing. Each replication was split into 5 six-row plots to be harvested at 2-week intervals after the first harvest on January 6. Only one other harvest (January 22) was possible because of freeze damage which occurred January 24. Tops of the plants down to 2 inches above the soil surface were harvested for dry-weight measurements. Soil and air temperatures at various levels were measured by thermocouples and potentiometric recording.

The oat experiment was repeated a second year using the same variety and procedures except replications were increased to 5. Before the oats were planted, 500 pounds per acre of 8-8-8 fertilizer was broadcast over the entire test area and 120 pounds per acre of nitrogen as ammonium sulfate was added as topdressing. Three harvests were possible before the experiment was abandoned because of freeze damage.

Effect of soil temperature as altered by row direction on rate of nitrification was surveyed in the first-year oat experiment.[3] Bags of soil containing ammonium sulfate were placed in the soil at 1½-inch depth between the rows of both north-south and east-west direction. At weekly intervals, bags from each location were removed and the amount of nitrification determined.

RESULTS AND DISCUSSION

As shown in Figure 1, lupine plants in rows oriented east-west cast a shadow across the soil to the adjacent row on the north. Plants growing in rows oriented north-south cast little shadow on the soil between the rows except in early morning and late afternoon (Figure 2). Because of the angle of incidence of the sun's rays on January 1, a plant 10 inches tall casts a shadow approximately 13 inches at midday (Figure 3).

Soil temperatures at 1-inch depth between rows oriented north-south were as much as 10 degrees higher on still-sunny days than soil temperatures at the same depth between rows oriented east-west (Tables 1 and 2). The influence of row direction on soil temperatures was greater at the 1-inch than at the 4-inch depth. Nevertheless, the soil in the north-south rows was as much as 2 degrees warmer even at the 4-inch depth. Temperature differences began to appear as early as 10 a.m. and reached maximum shortly after midday. In general, the influence of row direction on soil temperature did not persist later than 5 p.m.

Air temperatures at 3- and 12-inch heights were higher in the lupine rows oriented north-south than in rows oriented east-west. The greatest difference did not occur until midday or later. The temperature data in Tables 1 and 2 represent maximal differences attributable to row direction obtained on clear, still days. The influence of row direction on temperature was not as great on cloudy and/or windy days.

Fig. 1.—Lupine in rows oriented east-west 1 p.m. December 20. Note shade between rows.

Since the rate of biological activity has been observed to double with an increase in temperature of 10° C (3), on the basis of temperature *per se* plant growth was expected to be improved in the rows oriented north-south. However, yield of dry material (Table 3) was significantly higher in the rows oriented east-west both years of the test. Yield of lupine was 17% higher in the more completely shaded, humid, and cooler environment of east-west rows than in the drier and warmer environment of north-south rows.

Fig. 2.—Lupine in rows oriented north-south 1 p.m. December 20. Note sun on soil between rows.

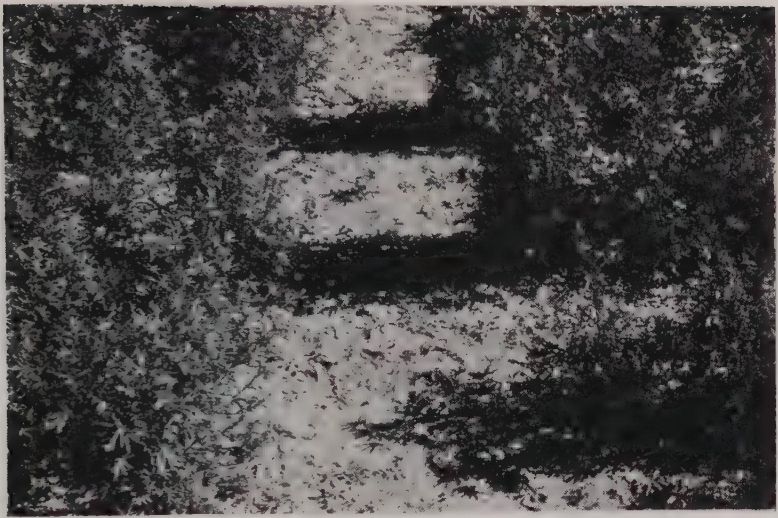

Fig. 3.—Shadow cast by 10-inch lupine plant 1 p.m. January 1.

All light falling on the soil surface is lost to the photosynthetic process. Since a definite increase in soil temperature was measured in the north-south rows, considerable solar energy is not being used in these plots for photosynthesis. This increased utilization of solar energy for photosynthesis in the east-west rows could easily account for the increased yield, in spite of a more favorable temperature environment in the north-south rows.

The possibility exists that the reduced yields in the rows oriented north-south could have resulted from the influence of row direction on soil moisture. Soil moistures were not measured, but the microclimate in the rows oriented north-south was characterized by conditions that would favor high water loss from the soil. Therefore, water would have become limiting in the north-south rows first.

Although only spot-check dew point data was obtained, that in rows oriented north-south was drier on sunny, still days than the air in rows oriented east-west. Lupine plants in the studies reported here were free from all diseases. Lupine was not damaged by low temperatures either year.

The effect of row direction on air and soil temperatures was not as great in the oat experiment as in the lupine experiment. The greatest effect of row direction on soil and air temperatures occurred at the 1-inch soil depth in oats 6 inches high (Figure 4). The Florad oats tillered profusely and by the time the plants were 10 to 12 inches tall, soil between the 10-inch rows was completely covered. Therefore, regardless of row direction the direct rays of the sun could not reach the soil surface and little or no difference in temperature would have been expected, nor would efficiency of light utilization have been much different. Oat yields were not influenced either year by row direction (Table 3). Likewise, no difference in nitrification rate could be attributed to row orientation.

Differential susceptibility to damage from low temperatures was apparent in the oats remaining on the plots after the first and second harvests.

TABLE 1.—TEMPERATURES AND DEW POINTS IN 11" WIDE ROWS OF LUPINE.

Location	Time									
	a.m.					p.m.				
	8	9	10	11	12	1	2	3	4	5
	Temperature °F*									
	December 18									
1" soil depth 3.5" from row										
N-S rows	36.5	40.5	47.0	52.0	57.0	65.0	65.5	60.5	57.0	54.5
E-W rows	37.0	40.0	44.5	49.5	53.5	56.0	56.5	57.0	56.5	54.5
1" soil depth 7" from row										
N-S rows	37.0	40.5	46.0	53.5	62.0	64.0	60.0	58.0	56.5	54.0
E-W rows	37.0	39.0	44.0	50.5	55.0	56.5	57.5	57.5	57.5	55.5
4" soil depth in rows										
N-S rows	41.0	42.0	44.0	47.0	50.0	52.0	55.0	55.0	55.0	55.0
E-W rows	42.0	43.0	44.0	46.0	49.0	51.0	53.0	54.0	55.0	55.0
4" soil depth 3.5" from row										
N-S rows	42.0	43.0	44.0	46.0	48.0	50.0	53.0	54.0	54.0	54.0
E-W rows	42.0	42.0	44.0	46.0	49.0	51.0	52.0	53.0	54.0	54.0
4" soil depth 7" from row										
N-S rows	42.0	42.0	44.0	46.0	49.0	52.0	54.0	54.0	54.0	54.0
E-W rows	42.0	43.0	44.0	46.0	49.0	51.0	53.0	54.0	55.0	55.0
Air temp. in center between rows, 3" ht.										
N-S rows	32.0	43.0	53.0	63.0	70.0	68.0	69.0	65.0	63.0	59.0
E-W rows	32.0	42.0	52.0	62.0	66.0	66.0	68.0	65.0	63.0	59.0
Air temp. in center between rows, 12" ht.										
N-S rows	34.0	45.0	54.0	62.0	67.0	68.0	69.0	67.0	67.0	62.0
E-W rows	35.0	45.0	54.0	61.0	65.0	68.0	68.0	66.0	64.0	61.0
Air temp. at 5' level	32.0	40.0	51.0	59.0	63.0	64.0	65.0	64.0	64.0	62.0
	January 12									
Dew point in center between rows, 3" ht.										
N-S rows							35.7			
E-W rows							42.5			
Dew point in center between rows, 12" ht.										
N-S rows							29.3			
E-W rows							32.3			

*Mean of two replicates.

Severe damage from low temperatures occurred both years in oats that had not been harvested and were approximately 14 inches tall (Figure 5). Oats harvested to a 2-inch stubble height 2 days before the low temperature occurred were killed. Oats harvested 2 weeks earlier had approximately 4 inches of regrowth and were not damaged. Unfortunately, temperatures in the microclimate were not measured on the date of the freeze; consequently, the effect of plant height on the microclimate at that time is not known. Since both the tallest and shortest plants were damaged, the effect of ground cover on re-radiation and temperature can be discounted. The resistance to freeze damage can more logically be attributed to the physiological condition of the plants when the low temperatures occurred. Row direction did not influence the damage.

Observations on differential susceptibility to damage from low temperatures support the conclusion that when small grains are clipped or grazed

TABLE 2.—MEAN TEMPERATURE AND DEW POINTS IN 11″ WIDE ROWS OF LUPINE.

Location	Time a.m. 8	9	10	11	12	p.m. 1	2	3	4	5
					Temperature °F*					
					December 19					
1″ soil depth 3.5″ from row										
N-S rows	36.5	40.5	47.5	52.0	56.5	65.5	66.5	61.0	56.5	56.0
E-W rows	36.5	39.5	44.5	49.5	52.5	55.0	56.0	57.0	57.0	56.0
1″ soil depth 7″ from row										
N-S rows	37.5	40.5	46.0	53.5	62.0	63.5	59.5	58.5	56.5	55.5
E-W rows	37.0	39.0	45.0	50.5	53.5	55.5	57.0	58.0	58.0	56.0
4″ soil depth in rows										
N-S rows	41.0	41.0	44.0	46.0	49.0	51.0	53.0	55.0	55.0	54.0
E-W rows	42.0	42.0	44.0	46.0	48.0	50.0	52.0	54.0	55.0	55.0
4″ soil depth 3.5″ from row										
N-S rows	42.0	42.0	44.0	45.0	48.0	50.0	52.0	53.0	53.0	53.0
E-W rows	41.0	42.0	44.0	46.0	48.0	50.0	52.0	53.0	54.0	54.0
4″ soil depth 7″ from row										
N-S rows	42.0	42.0	44.0	45.0	49.0	51.0	53.0	53.0	54.0	53.0
E-W rows	42.0	42.0	44.0	46.0	48.0	50.0	51.0	53.0	54.0	54.0
Air temp. in center between rows, 3″ ht.										
N-S rows	32.0	44.0	57.0	63.0	66.0	70.0	69.0	67.0	62.0	60.0
E-W rows	31.0	43.0	55.0	62.0	65.0	63.0	69.0	66.0	63.0	58.0
Air temp. in center between rows, 12″ ht.										
N-S rows	34.0	45.0	57.0	66.0	66.0	70.0	69.0	70.0	69.0	65.0
E-W rows	34.0	45.0	57.0	65.0	63.0	61.0	66.0	66.0	64.0	64.0
Air Temp. at 5′ level	34.0	41.0	52.0	63.0	62.0	65.0	64.0	68.0	66.0	65.0
					January 23					
Dew point in center between rows, 3″ ht.										
N-S rows							62.5			
E-W rows							66.5			
Dew point in center between rows, 12″ ht.										
N-S rows							61.0			
E-W rows							62.5			

*Mean of two replicates.

TABLE 3.—DRY WEIGHT OF BLUE LUPINE AND OATS IN ROWS ORIENTED NORTH-SOUTH AND EAST-WEST

	1st Season[1] lbs./acre		2nd Season[2] lbs./acre		
Lupine			Harvest dates		
	Jan. 26	Feb. 18	Jan. 30		
N-S rows	1629	2160	2366		
E-W rows	1646	2360*	2835*		
Oats			Harvest dates		
	Jan. 6	Jan. 22	Dec. 19	Jan. 5	Jan. 20
N-S rows	758	1895	928	1615	2570
E-W rows	807	1766	982	1705	2470

*Significant .05 level of probability.
[1]Lupine values mean of 6 replicates; oat values mean of 4 replicates.
[2]Lupine values mean of 7 replicates; oat values mean of 5 replicates.

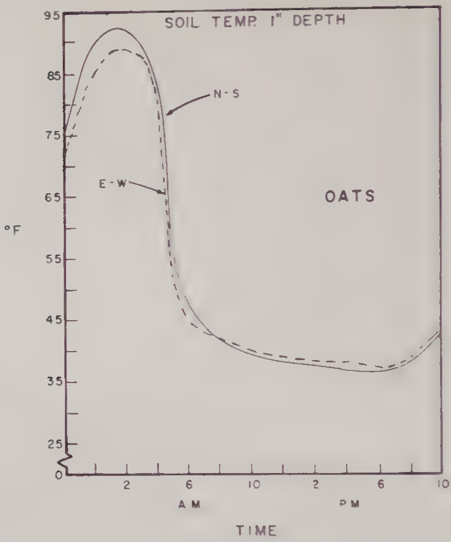

Fig. 4.—The influence of row direction on soil temperatures in oats 6 inches high in rows 10 inches apart. Data taken on a clear, sunny day and represent the mean of two replicates.

Fig. 5.—Winter injury to oats. Plants in center clipped 2 days before freeze were killed. Plants on left, not clipped, were damaged but all survived. Plants on right clipped 2 weeks before freeze were not damaged.

in the winter, there is a critical height of cut or grazing for minimum damage from freezing. Furthermore, damage from low temperatures can be reduced if sufficient regrowth is allowed.

SUMMARY

Shadows cast by lupine plants in rows oriented east-west lowered soil temperatures at 1-inch depth as much as 10° F at midday on sunny, still days. Even at the 4-inch depth soil temperatures in the east-west rows were 2° F lower than temperatures at the same depth in north-south rows.

Air temperatures in lupine rows oriented east-west were lower than temperatures at the same location in north-south rows. The effect of row direction on air temperatures was not as great as that on soil temperatures.

Humidity was higher in east-west rows than in north-south rows.

That the yield of lupine was significantly greater in the east-west rows than in the north-south rows both years of the tests is probably due to an increased efficiency of light interception.

The influence of row direction on soil and air temperatures as measured in the experiments reported here was not as great in oats as in lupine. Yield of Florad oats and soil nitrification were not affected by row direction.

Severe freeze damage occurred in oats clipped to 2-inch stubble height 2 days before freezing temperatures prevailed. Non-clipped (14 inches tall) oats were damaged slightly by the freezing temperatures. But, oats which had been clipped to 2-inch stubble height 2 weeks before the low temperatures occurred were not damaged. Similar freeze damage occurred both years of the test.

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The New Trend in Fiber Processing Technology[2]

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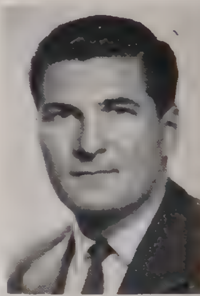
GENERAL INTRODUCTION



In order to appreciate more fully all the aspects of this technical paper it is well to review briefly some of the basic facts, well known in the art, concerning the various types of staple fibers. The traditional, as well as the novel methods of their processing into end use fabrics, both of which are subjects of this study, will be discussed.

Major Classes

From the humble beginning of the art of spinning and weaving, the classifications of staple fibers have been conveniently grouped under three major headings, according to their origin, namely: vegetable, animal and mineral.

VEGETABLE ORIGIN—Within this group there exists a further distinct subdivision into SHORT staple fibers, which include cotton and wood pulp, and LONG staple fibers which in turn comprise bast fibers, such as flax, jute, hemp, ramie and kenaf and leaf fibers, also referred to as hard fibers, with sisal and sansevieria serving as examples.

ANIMAL ORIGIN—Wool is the leading example of fibers in this group.

MINERAL ORIGIN—Asbestos fibers are in this group.

More recently, the CHEMICAL ORIGIN group has been added to the foregoing classifications. Fibers in this group are generally referred to as man-made staple and filament fibers.

Staple fibers are characterized by having a finite length or length ranges, which necessitate a diversity of methods and machine equipment for their processing, in addition to that required by their varying physical properties.

Staple Fiber Processing Systems

Several basic systems have been developed for processing various groups of staple fibers with similar characteristics. In practice, however, some of

[1]Presently in the final year of studies and research for the Ph.D. degree at the Pulp and Paper Research Institute of Canada and McGill University on the "Turbulent Flow of Model Fiber Suspensions" under the supervision of Dr. W. H. Gauvin, head of the Institute's Chemical Engineering Division.

[2]This paper is essentially an updating of one on the same general subject presented at an earlier meeting of the Society in St. Petersburg by Emilian Bobkowicz and published in Proceedings Volume 18, 1958. Its presentation on our forum would seem to be justified not only by the vigorous newness of the fiber processing method discussed and the tremendous economic impact it might well have on national and world industry in this field but also, and of course more importantly, the potential relation of this process to Florida's rapidly growing interest in two bast fiber crops of great promise, ramie and kenaf, the latter well-known in the fiber markets of the world as a substitute for or an extender of jute. Ed.

these systems had to be modified and adapted to meet special processing requirements, as for instance, in the case of long staple hard fibers and the softer bast fibers.

There are five major and well established fiber processing systems. As can be readily seen below, these systems increasingly overlap each other in the processing of some fibers.

COTTON SYSTEM—The cotton system, as the name implies, was developed initially for processing cotton fibers into yarn. The staple lengths processed range from 13/16 to 1-9/16 inches, and up to 3 inches with minor modifications.

AMERICAN SYSTEM—This is a refined and modified version of the cotton system for fibers from just under 3 inches and extending up to 9-10 inches staple length.

WORSTED SYSTEM—Used for long staple fibers in the range as low as 3 inches and as high as 15 inches, this system is suitable for wool, man-made staple fibers, ramie and other fibers.

WOOLEN SYSTEM—This system is particularly suitable for coarser wool, other fibers and their blends (1).

WET PAPER SYSTEM—Especially adapted for processing short wood fibers, ranging in length from 1/64 to 1/4 inch, this system can now also be utilized, with modifications, for the production of nonwoven fabrics comprising staple fibers up to 1/2 inch in length.

Conventional Staple Fiber Processing Stages

In most cases, all staple fibers, except wood, which are processed in the conventional manner, pass through the following sequence of major operating stages.

FIBER TO SLIVER STAGE—includes opening, blending, cleaning, picking and carding.

SLIVER TO YARN STAGE—comprises multistage drafting, roving production, spinning and winding operations.

YARN TO FABRIC STAGE—incorporates yarn winding, warping, slashing, weaving, finishing and fabric winding.

Future Research

From the preceding it becomes evident that there is no universal method which is suitable for processing all of the wide range of staple fibers. It is also evident that all the various conventional systems involve technologically complex operations and equipment.

Although marked improvements have been made in this equipment during the last few decades, particularly in improved and more efficient cleaning, carding, high-speed drawing, roving, spinning, winding, warping, slashing, weaving and in fact, in practically all steps in mill processing equipment, this traditional approach of the textile industry of improving phases of processing, rather than the processing system as a whole, has reached a point where the feasibility of a further drastic increase in product quality or reduction of processing costs has become either uneconomical or problematic because of technical limitations encountered.

Thus, in spite of outstanding improvements in individual machines,

staple fibers are still processed into fabrics by the conventional systems based on the use of complex, discontinuous, multistage operations. A modern cotton mill utilizes as many as fifteen processing stages involving an excessive amount of costly labor (2).

Textile research during the last 200 years has been of an evolutionary nature and was primarily directed towards the development of improved fiber processing equipment and economical methods of raising the quality and lowering the cost of ultimate products. In the eyes of some textile experts and leading North American textile research institutions, what is needed now is a fresh approach and a break from traditional thinking. What is being quoted as the number one need of the textile industry is a series of breakthroughs in machinery, brand new and radical concepts in manufacturing and complete elimination of some of the traditional processing steps (2,3).

CURRENT FIBER PROCESSING TRENDS

The revolutionary developments and progress in textile technology by the chemical, and to some extent also by the electronics industry, during the last few decades have been, to a large degree, the stimulating factors in the creation of new and varied approaches in textile fiber processing machinery and techniques, which in some cases incorporate radically different concepts. According to obtainable information these new trends apparently follow a few main avenues of development, each of which in turn branches out in many directions.

The main development lines may be listed as follows:

Automation and higher speeds of conventional systems.
Nonwoven fiber fabric production.
New yarn making system.
Nonwoven yarn fabric production.

The secrecy which generally surrounds the development of such work, most of which is patented, makes it a difficult task to evaluate its real merits. However, some recent and more frequent disclosures from various sources should make it possible to understand, to some degree at least, the potentials of some of the main developments.

AUTOMATION AND HIGHER SPEEDS OF CONVENTIONAL SYSTEMS

The need for technological breakthroughs in textile processing is being voiced by leading U.S. textile men. Nonetheless, within the complex conventional processing systems, the search still goes on for better machinery, higher speeds, simplification and automation of processing stages by adaptation of automatic devices and electronic monitoring equipment, and last but not least, for complete elimination of some traditional steps.

Fiber to Sliver

Leading cotton-textile machinery manufacturers in Switzerland and Japan claim the development of new, fully automatic continuous processing from fiber to sliver systems (4-6). According to Swiss claims the picker lap will disappear and cotton processing will be continuous from opening

through carding. With the advent of their automatically controlled and integrated machine group, there is *no handling of cotton from bale through carding*. The first machine in this set-up is called a "Carousel," in which the cotton is plucked by four beaters from twelve bales which move in a circular path over the beaters—like a merry-go-round, and hence the name.

Following the Carousel, comes the Automixer, to which the cotton is transported pneumatically. This is primarily a mixer or blender for cotton from the individual Carousels, of which there may be one or several, and reworkable waste may be added here. Next comes a cleaner and then the picker, but following the second beater section, no lap is formed; the cotton is caried in loose condition through ducts or channels and dropped into a vertical reserve box over the licker-in section of each card. The cotton is under electronic control at every step. The amount of cotton in the reserve boxes over the cards is controlled, and the excess goes to the backs of the pickers (4).

The Japanese system is claimed to perform all the above functions, but also incorporates a card sliver conveyer device, thus even eliminating coilers, to transport individual slivers to high speed drawing frames with automatic evenness control (5).

It is claimed and expected that the above developments will save up to 50% of the labor costs involved in the "fiber to sliver" processing stages. It will result, besides, in greater uniformity of slivers and consequently of the yarns as well.

Both these systems are now under pilot production tests in Switzerland and Japan. An installation of the Japanese system on a pilot plant scale is now apparently under construction in the U.S.A.

Improved Carding

In the above automatic systems, however, the bottleneck of conventional processing, the slow carding operations, has not been eliminated. The processing of cotton, which accounts for about 65% of all fibers consumed by the textile manufacturing industry (7,8) is a case in point. The cotton card of today is essentially the same as designed and built in the late 1800's. There still is, however, a considerable amount of research and development going on in this field, aimed at the development of high-speed, more efficient cards.

The Granular Card can be cited as an example of this trend. The Granular Card is a standard flat top card on which the flat assembly has been replaced with an air-tight cover with an aluminum oxide carding surface closely spaced to the main cylinder. Advantages claimed are, lower processing costs, flat waste eliminated, dust and fly practically eliminated, card weight is reduced by about 800 pounds and product quality remains about the same (2).

A more recent development in the U.S.A., the Duo Card system, is said to be the first breakthrough in carding methods since the design of the first flat type card. The Duo Card system is effected by connecting two conventional cards in a tandem arrangement, whereby the carded fibers of the first card are continuously and directly transferred to the second cylinder. This high speed transfer of the carded fiber is allowed by replacing the licker-in on the second card by a doffer. The second card provides the finishing carding action for the fibers before they are delivered to the coiler; it acts as an evener and blender and consequently is more positive in waste and nep removal (9).

The claimed advantages of this system are increased production by about three to one, space saving and improved quality. In actual mill tests, production rates of up to 56 pounds per hour have been obtained. With further improvements, which are still in the development stage, and increased web doffing speed, a further considerable increase in output is considered possible. It is conceivable that this high speed carding system may find application in the automatic fiber to sliver production set up discussed earlier.

Consideration is also given to a wide range of radically different approaches by new concepts of fiber aligning and sliver forming. These investigations include a.o. aerodynamic (already successfully applied in nonwoven fabric production), electrostatic, hydrodynamic, ultrasonic and chemical working principles and possibilities.

Sliver to Yarn

In the "sliver to yarn" stages of processing, the greatest achievements in recent years have undoubtedly been in the drawing operation. The development of high speed drafting, combing and super-high draft spinning machines, which in some cases enable the elimination of the roving operations as well, has increased yield and greatly improved quality (10).

The spinning operations, however, are still handicapped by technical limitations. Increased processing speeds are limited by the necessity to use travelers, spinning rings, and the resulting ballooning of the yarn is particularly encountered as a problem in the trend towards large yarn package production with its economical advantages.

Research in this field is primarily concentrated on the development of spinning machines with considerably higher spindle speeds or ones in which the use of travelers or rings, or both, will be eliminated and in which automatic doffing will be incorporated. It is an established fact in the art that the optimum technically feasible speed of a traveler is about 1 mile per minute. Hence the larger spinning ring, particularly in large package production, the lower will be the optimum spindle speed. The traveler and spinning ring are thus major roadblocks to higher spindle speeds in the conventional yarn making systems (11).

This work is apparently paying off with the announcement in Japan of a new type of two-in-one travelerless ring spinning device capable of running at speeds approaching 14,000 r.p.m. Consisting of an outer ring, which is a permanent magnet, and an inner ring, which floats in the magnetic field of the outer ring, the device imparts twist to the yarn without recourse to a traveler, as it passes through the gap between the two rings (12). North America claims at least two new developments. The first of these, presently undergoing tests, apparently replaces the traveler and spinning ring by a revolving tube with a slot through which the yarn passes. The twist is imparted to the yarn by friction in the slot of the revolving tube. The second development is claimed to be a universal spinning device, which can impart any desired amount of twist to any type of roving or tape. This is done at super high speeds, without ballooning, without either traveler or ring, on a fully integrated compact unit which incorporates adjustable and fully automatic twisting, traverse yarn package build up, collecting and automatic doffing devices. Further, it enables the making of heat-set stretch yarns in one operation on the same patented device (13). Now under extensive pilot production tests, it is apparently giving very satisfactory results.

This universal spinning machine, in combination with the earlier mentioned "fiber to sliver" system, may well lead to a fully automatic continuous "*fiber to yarn*" processing development, within the conventional system of fiber processing.

Yarn to Fabric

In the "yarn to fabric" stages, the traditional bottleneck of "interlacing" still prevails. In spite of the development of the automatic cop or shuttle-changing looms and more recently of the complex and costly automatic shuttleless looms, the speed of production of weaves is still exceedingly low, in the range of up to 320 picks per minute. The limiting factor is the necessity of interlacing of yarns to form a conventional woven fabric. Knitting, a somewhat faster method of fabric forming, is making heavy inroads into the textile markets. although this method also encounters technical limitations to further substantial production speed increases.

NONWOVEN FIBER FABRIC PRODUCTION

The modern approach of processing staple fibers into nonwoven fabrics is often considered as the only really new development in the textile industry since mechanical textile processing began, even though felt fabrics, the first nonwovens, derived from animal fibers, have been well known in the art to the past generations. The prospect of producing textiles without the complex conventional spinning and weaving, was and is an exceedingly intriguing technological venture for the textile, paper, and related industries all over the world.

Nonwovens may be defined as coherent webs of entangled and/or bonded fibers preferentially or randomly arranged, without the fibers first being spun into yarns and later interlaced either by weaving, knitting, braiding, or by any other means of yarn manipulation into conventional woven fabrics. Controversy exists about the exact definition of nonwovens, which seems to depend mostly on who is doing the defining (14).

In this modern approach of entirely by-passing the processes of spinning and weaving to form self-supporting webs of fibers, the nonwoven fabric manufacturers have been, and are being decisively aided by the rapid progress of the chemical industry in the development of a wide range of binders in resin and fiber form.

Basically, nonwovens are manufactured by forming a web of one or more fiber layers in which the fibers, arranged in a random, crosswise or parallel orientation, are bonded together at their contact points. Bonding is usually achieved with the aid of a thermoplastic or thermosetting agent, or blends of both, in resin or fiber form preferably with application of heat and pressure.

Nonwovens are comprised of two major components: the web and the binder. The final characteristics of a nonwoven fabric depend, to a large degree, on the base fiber used as well as on the nature of the bonding agent and production technique applied. Many methods and varied types of machines are utilized in the making of nonwovens. The diverse and changing end use requirements lead to varying methods of production and equipment design.

There are today two basic methods of web formation, namely the "dry" textile and the "wet" paper systems.

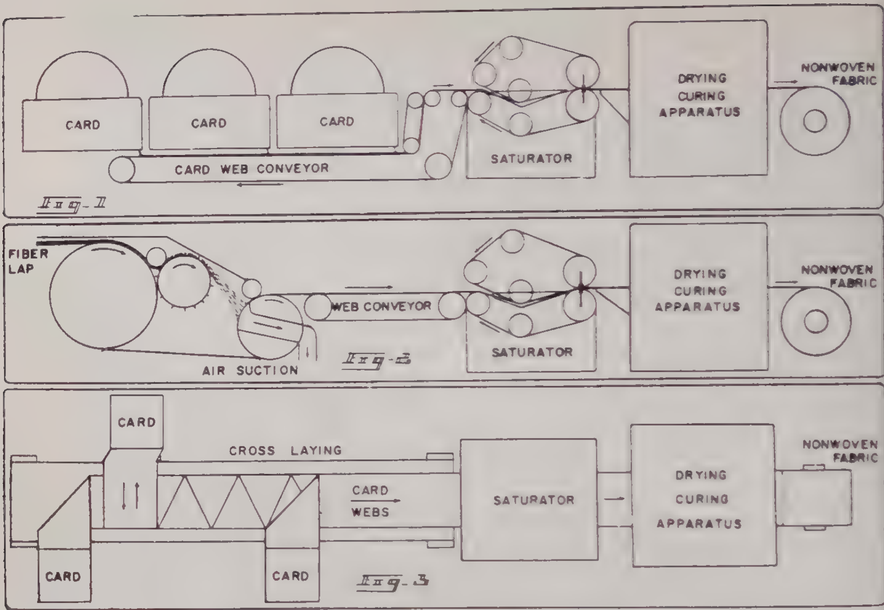


Fig. 1.—Card and Garnet Method of Web Formation.
Fig. 2.—Aerodynamic Method of Web Formation.
Fig. 3.—Cross Laying Method of Web Formation.

DRY TEXTILE WEB FORMATION

Card and Garnett Method (Fig. 1)

To manufacture nonwovens with a substantially parallel arrangement of fibers, a tandem line of cotton cards is preferred (1). This primarily concerns staple fibers which possess properties rendering them suitable for processing by the cotton system. In cotton card webs the fibers lie nearly parellel and, although the web has almost all of its strength in only one direction, it leads to a fabric with a cloth-like texture of great lengthwise strength, which is preferred in many end uses. On the other hand, where a greater flexibility in use of various types of fibers and a more random distribution of the fibers in the web are of primary importance, garnetts, worsted and woolen cards are used to form the web. The latter appear to have an advantage over cotton cards in that they have a larger output per hour and can deliver wider web widths. They are more versatile in that they can handle a greater variety of fiber descriptions with satisfactory uniformity, with less parallelization of fibers so as to step up transverse strength of the web (15). Depending upon the desired weight and type of nonwovens to be produced, similar or dissimilar fiber webs from one or more cards, or garnets, may be joined together to form the fiber webs sought.

Aerodynamic Method (Fig. 2)

To form a web of randomly arranged fibers, they are blown in an air stream and deposited in a random manner on a rotating screen. The fibers are substantially evenly collected on the screen by means of suction exerted

from within the screen. The fiber web, consequently obtained by doffing the sheet off the screen onto a conveyer and suitably bonding it together at a subsequent station, has good uniformity and almost equal strength in all directions. Commercial equipment to do this is available, and some manufacturers have developed their own systems. (1, 16-18).

Parallel arrangement of fibers apparently can be achieved also by using the areodynamic method. An appropriately grooved take up cylinder is used, where the suction force is exerted at the bottom of the grooves (19).

Cross Laying Method (Fig. 3)

In this method a card web is fed into a lapper which continuously crosses and folds the web. In this way the fibers of one web can be made to lie at crossed angles to one another. To obtain an unbroken and even surface on both sides of the nonwoven produced this way, and to arrive at a higher degree of random orientation of the fibers, the cross lapped card web may be sandwiched between two unidirectional card webs. The chief disadvantage of this method is that it is impossible to make extremely light-weight combinations since at least three and preferably four layers are required.

Also, due to the cross lapping action and the attention which must be paid to matching the edges of the web being cross lapped, the forward speed of motion of the finished fiber web is painfully slow. This method, however, does provide a means of securing a more balanced strength in both longitudinal and transverse directions, thus overcoming one of the principal criticisms of many nonwoven fabrics.

BINDING METHODS FOR DRY WEB FORMATION PROCESSES

Nonwoven fabrics have been called chemically woven fabrics with good reason. The binder plays an important role in the success or failure of a nonwoven material and is considered the key material in the production of modern nonwoven fabrics.

The choice of a binder as well as its method of application will depend on the fibers to be used and the end use of the fabric. One binder and method of application may suit several fibers and a number of end uses, but often, a particular combination of fibers, binders and application methods is required to obtain the best result. Generally speaking, binders most closely related chemically to the fibers are the logical prospects for most success.

Based upon the physical state of the binder, the most commonly used methods of application can be separated into two broad classifications: wet and dry systems. The wet systems include both aqueous and non-aqueous solutions as well as dispersions or emulsions of the binder, whereas the dry systems mainly comprise thermoplastic and thermosetting resins in the form of powders, fibers, films, etc.

Wet Systems

NON-AQUEOUS SOLUTIONS—Only a few types of nonwovens are made which utilize binders in solvent solution form. Although efficiency of the process and the quality of the end product are considered good, the major problem comes from the use of non-aqueous solvents with the ever present hazards of both toxicity and fire. Besides this, the use of solvents is costly, unless recovery systems, which are also expensive, are available.

WATER SOLUTIONS—Water solutions of natural gums, proteins, starches and some synthetic water soluble polymers are limited in use as binders. They find application where stiffness can be tolerated and cheap price is of major importance.

EMULSIONS—The water-based emulsions, which include the polymer latices, are considered the most versatile and popular of the nonwoven wet binders. They comprise the largest class of binders for nonwoven fabrics and commercially are the most important. A wide range of properties, ease of handling and the variety of materials that lend themselves to this type of application have made emulsions popular. All the synthetic latices, such as polyvinyl chloride, polyvinyl acetate, nitrile, polyacrylic, polychloroprene and the GR-S types, and natural rubber fall in this class. They may be applied to the web by saturation, as a spray, in foam form or they may be printed or padded onto the web. In each case the web is first dried, heat bonded and if desired, calendered. Bonding temperatures range from about 200-600 F. depending on the fibers used and bonding agent applied.

Dry Systems

POWDERS—Attempts have been made to use binders in powder form. Advantages of powder bonding are relatively low cost and ease of application to inner parts of the structure which do not readily allow wet processing. Use of this system, however, is as yet very limited. Powder resins are satisfactory for binding, but the problems of distributing the powder into the web and keeping it where it can best bind the fibers efficiently make this process unattractive at the present time.

FIBERS—On the other hand the use of thermoplastic fibers as a bonding agent is considered a practical and effective way of obtaining well bonded nonwovens. In this method, thermoplastic fibers are blended with the base fiber during web formation. As these thermoplastic fibers have a lower softening point than the remainder of the web, bonding is accomplished by heating the web to this low softening point of the binder fibers. Pressure may or may not be applied during heat curing, depending on the kind of end product desired. Embossing techniques are often used. Thermoplastic fibers offer a number of special advantages as binders. The exact amount of binder used can be determined and its distribution can be closely controlled. By this method nonwovens with a pleasing hand, good drape and many other desirable characteristics can be tailor made to requirements. Some of the drawbacks of fiber binders are higher cost than comparable liquid binders and the fact that to have a low melt temperature, the polymers are usually low molecular weight and thus have inherently low strength. Such fibers generally are not suitable where high strength at minimum binder weight is required.

For further reading on the above discussed and other binding methods, reference is made to a series of background articles (20-24).

Other Systems

In addition to the above dry and wet bonding techniques, a very strong trend now exists towards the development of wholly new binders and methods which could further accelerate the already rapid expansion of nonwovens into many markets, hereto the traditional domain of conventional textiles. It is well to mention some of these developments.

FIBRIDS—These are new synthetic thermoplastic fibrous particles, given the generic name of "fibrids" which are being used as binders in nonwoven fabric production. Reference shall be made to these binder particles later on and in more detail as part of the discussion of the wet paper process.

RAYON BINDER—A wholly new development in this field is a non-thermoplastic, multicellular, self-bonding viscose rayon fiber which can be formed into a web on either the dry or wet paper system. It forms a secure bond merely by being wetted in water, without the need of heat, pressure or chemicals.

CHEMICAL BINDER METHODS—A new chemical method is one which uses as binder a latex of a polymer containing a carboxyl group and a particular type of "cross linking agent," i.e. a multi-functional monomeric material, that will react at relatively low temperatures with the polymer and thus "cross-link" the polymer chains with each other making the polymer even more insoluble. This binder system of a patented invention cures at temperatures as low as 210° F. to give good washfastness to nonwovens. The new binder system is claimed to provide as good, or better, washfastness and hand, as any prior bonding process in the art and at the same time it apparently permits greater speed and lower costs by providing a binder system that cures either at a relatively low temperature or in a shorter time at the more conventional high temperatures (25).

Another chemical bonding method is the "salt bonding" technique where use is made of the fact that water solutions of certain salts at high concentrations are swelling agents or solvents for the fiber-forming organic polymers. Treatment with these join-inducing salts leads to self-bonding of fibers at the points where the fibers intersect each other. The resulting sheets of nonwoven material exhibit high strength, folding endurance and stability (26, 27).

NEEDLE PUNCHING SYSTEM—Applying the age old felting principle to modern processing methods resulted in the development of the needle loom. The needle loom is essentially a punch press in which a reciprocating crosshead holding many barbed needles punches them through the web of fibers or batt being processed. The barbs on the needles engage the fibers and push them through the mass of material to interlock the individual fiber strands with each other thus completing the three-dimensional fiber entanglement which gives the structure its unique fiber cohesion (1, 14, 28).

This process has gained wide acceptance in the past few years. One particular use of the needle loom in a patented process is to needle punch a previously bonded nonwoven material, thus bringing the individual fibers through the bonded surface layer. This causes them to form a new outermost surface layer, hiding the existence of the adhesive binder, and results in the formation of a nonwoven fabric of high strength and dimensional stability. About 70% of strength and dimensional stability derives from the needling action and the remainder from the adhesive. This fabric has an all-fiber surface, obviating the resiny paper-like feel of some nonwovens, and can range all the way from an extremely soft hand to board stiffness. Weights can range from 1 ounce up (29-31).

Bonding Agents

Apparently the ideal bonding agent for nonwoven fabrics is not yet at hand. The chief characteristics which such a binder would have to possess are considered: high strength, ease of uniform application to the web, high specific adhesion to the individual fibers, good elasticity and elastic recovery. Finally, and depending on the intended field of application, the binder should be light, wash- and clean-fast, should be free of discoloration, and should exhibit good dimensional stability. The web incorporating the binder should have good crease resistance, resilience, softness, hand and feel, and for certain uses should be heat-sealable.

Most important, and also one of the greatest problems in the production of nonwovens, is the choice of a suitable binder. Compromise is the key word. Adequate strength usually means poor absorbency and a papery hand. Adequate softness or drape is accompanied by poor durability and general structural weakness. The very binders which are used to impart integrity to webs at the same time create other properties which are undesirable (32).

Either thermoplastic or thermosetting resins can serve as binders. Among the latter *melamine-formaldehyde, methoxylated urea-formaldehyde* and *ethylene urea-formaldehyde derivatives* are the most important. They are particularly of interest in the production of nonwoven fabrics of high cellulose content to which they impart greater crease resistance and resilience as well as improved wet strength. On the debit side is the fact that they have a tendency to stiffen the fabric, a proneness to discolor and susceptibility to chlorine attack.

Within the group of thermosetting binders there are, of course, wide variations. *Melamines* are the most commonly employed agents in this category, principally because of low cost and their high bonding and mechanical strength, which is due to the extensive cross-linking in such resins. However, they are especially susceptible to chlorine attack and discoloration.

Thermoplastic binders occupy a more prominent place than thermosettings. Evaluations made show very pronounced differences in the desirable key properties of nonwovens treated with different thermoplastics.

In case of acetate-cotton blends, best all-round performance was shown by *butadiene-acrylonitrile* which proved, however, only fair in colorfastness. The excellent fastness of *acrylic resins* is bought at the cost of mediocre resilience and heat sealability. Each of the thermoplastics must thus be evaluated in the light of the desired end result. Often benefits may be gained by using two thermoplastics jointly or even a thermoplastic in conjunction with a thermosetting resin.

The latter approach is particularly advantageous in areas where both good durability and crease resistance are important factors, as for example in production of nonwovens for apparel purposes.

Polyvinyl chloride is useful where high tensile strength is called for. This polymer, however, must be stabilized against oxidative degradation. The main attraction of *polyvinyl acetate* is its low cost and high original strength and it is thus especially useful as a binder in disposable items. Its main drawbacks are poor washfastness, softness and resilience. It is used where freedom of odor and taste are important.

Among synthetic rubber-type latices, *butadiene-styrene* is favored by low cost and good resilience, initial softness and washfastness but, due to

oxidative instability, it can serve only where severe discoloration and subsequent stiffening is permissible. Excellent wash- and clean-fastness is exhibited by *butadiene-acrylonitrile* copolymer latices which are also characterized by good resilience. For softness of feel and for stability in use, this type of resin is often internally plasticized when used for nonwovens which require dimensional stability in use, as is the case in items for the apparel trade.

A considerable range of properties is available for *acrylate esters*. Their characteristics for binder purposes may be varied widely by choice of different monomers in this family and by adjustment of the polymer's molecular weight (15, 20, 22).

In the dry web bonding field, thermoplastic binders in the form of fibers are most important. Polyvinyl chloride, polyethylene, vinylidene polymers and copolymers, and special low melting point acrylic, polyester and polyamide fibers are but a few examples of thermoplastic fibers that may be used very successfully as binders. To this group we also have to add the recently developed "fibrids," which are thus far available in nylon, acrylic and polyester fiber types. The nonthermoplastic multicellular self-bonding viscose rayon fiber, mentioned earlier, constitutes a special and new type of binder.

Experience has shown that on the whole in order to obtain the best end products, the binding fiber should be chemically similar to the base fiber.

The amount and type of binder employed cannot be arbitrarily set. The end use of the product determines the binder, its modifications, as well as the binder to fiber ratio. It is important, however, to point out the basic, hitherto unchanged fact about nonwovens: because of the presence of a "binding agent" the mobility of a fiber is lost in a bonded fabric, and the softness factor is sacrificed. In order to obtain drapability, suppleness and softness in a nonwoven fabric approaching that of a woven fabric, more efficient binders are needed which will provide similar strength when used in smaller quantities. The chemical industry has expended a great deal of research and development effort in a continuous attempt to satisfy the requirements of many of the newly developed nonwoven fabrics (22).

WET PAPER PROCESS

The development and the rapid growth of nonwoven fabric production in recent years has stimulated interest in the use of papermaking equipment for the manufacture of these materials. Nonwovens are viewed by paper manufacturers as a suitable area for profitable diversification. The main attraction of some of these products is their adaptability to high speed papermaking techniques and their high unit value as compared with paper.

Paper experts are very optimistic and see an almost "unlimited" future for nonwovens produced by the wet paper method in such end uses as aprons and coats for supermarkets, restaurants, and research labs, for draperies, table cloths, overalls for workers, bed sheets, cushion covers, ladies dresses, shirts, wallpaper, packaging, artificial leather, carpet backing, automotive and many other industrial, military and home uses.

This wet process, however, has a serious technological drawback. At present, when fibers having a length to diameter ratio in excess of 500 are used, uniform dispersion of the fiber becomes a major problem. In effect

the fiber length is thus limited to 1/4 inch for wood fibers and 1/2 inch for cotton and man-made fibers in the 1 to 3 denier range. This is well below the inch minimum fiber length which is called for by most marketable nonwoven fabrics. Cotton fibers are the most difficult of all common fibers to handle in a liquid suspension, since they also have a tendency to shrink and curl. At the dilute consistencies and turbulence levels associated with the wet process, the presence of overlength fibers may result in the formation of the so called dumb-bell fiber bundles. To enable the use of fibers, even with the above-mentioned limited range of lengths and deniers, and to prevent their flocculation tendency by use of controlled turbulence and additives or deflocculation agents, vigorous research and test programs have been undertaken by the paper industry (33-35). Hydrodynamic behavior of man-made fibers in papermaking size is also under study (36-38).

The feeling apparently prevailing among papermaking experts is that these technological obstacles offer a challenge which will be overcome with further research, which in turn will provide means and ways of web forming and bonding which will successfully utilize the wet paper process, with its higher production rates and lower costs, in the manufacture of a wide range of nonwoven fabrics. Paper makers in many countries are beginning to work longer staple fibers into their processes (39). According to some, there seems little doubt that Fourdrinier and wet web layers of the Rotoformer type, when further improved, will make a considerable imprint on the present day dry-web forming processing of the carding and aerodynamic types (40, 41). Understandably, the advances of the paper industry are viewed as a threat by the textile manufacturers, and yet as one of their number complains, the textile industry is on the threshold of a dynamic new era, which it seems most reluctant to enter (42, 43).

Past work with synthetic fibers in paper has pointed out that these fibers, unlike the natural papermaking fibers, have no inherent bonding power and that separate binders must be used to tie the fibers together. Several methods of bonding of fibers have been developed for the wet paper method. These include 1) resin bonding, 2) thermoplastic fiber bonding and 3) solvent bonding.

As in the dry methods, the key to successful production of nonwovens by the wet paper process lies in the proper choice of fibers and in effective bonding.

It has been shown that the final properties of the nonwoven fabric depend to a large degree on the binder properties themselves. In many cases, the resin and fiber binders used proved to be the weakest parts of the formed sheet.

In the opinion of Dr. K. R. Fox, Vice President of Fabric Research Laboratories, the biggest single boom for the field of nonwovens would be the development of a low cost man-made fiber with simulated felting properties (32). It now appears as though such a bonding agent, with the added facility of being heat sealable, has been developed, and is turning out to be the key to successful nonwoven fabric production by the wet paper method.

The result of research and development carried out by a major U.S. chemical corporation, is a new group of binders which have been given the generic name of "fibrids." Since a wide range of materials can be made from synthetic fibers and fibrids, a new generic term has been adopted for these products, namely "textryl" (44-48).

Fibrids are filmy or fibrous synthetic polymer particles, somewhat similar to beaten wood pulp. They can be made from virtually any synthetic polymer. It is therefore possible to prepare fibrids which are chemically similar to the base fibers used in the nonwoven fabric. Being excellent adhesives, there are few surfaces to which fibrids will not stick when properly applied and heat fused. Because of their form when combined with other staple fibers and laid down on the paper machine wire, they form a sheet which, when dried, develops adequate strength for winding up and subsequent handling. Full sheet strength is then developed by fusing the fibrids, at about 400°F., either in a heated calender or in the absence of pressure, in the latter case a much more bulky, soft and more drapeable sheet being obtained.

Standard papermaking equipment can be used to manufacture textryls. Fourdrinier machines have proved to be very satisfactory and limited work with cylinder machines and Rotoformers indicates these machines would also handle textile fiber and fibrid blends satisfactorily. Depending upon the desired properties of the nonwoven fabric, the manufacturer may add from 10 to 40 per cent fibrids to the synthetic or other fibers, such as cotton, rayon and wood pulps, or their blends.

At least six leading paper companies in the U.S.A. are already offering textryls for a variety of uses ranging from apparel interlinings to electrical insulation materials for motors and transformers. Thus, these newly developed nonwovens are actively competing with woven and other nonwoven fabrics when chemical properties are available at a cost advantage.

The uniformity and high strength achieved by the wet process using this method are truly remarkable, as for instance, in the case of the polyester textryl. Nonwoven fabrics of only ½ ounce (per square yard) weight have even been successfully produced at the high speeds of a paper machine.

The chemical industry is largely responsible for the spectacular development of a wide range of thermoplastic and thermosetting binders and of the improved versatile methods of their application, which has taken place, particularly during the last decade. This, in turn, was instrumental in the rapid growth of nonwoven fabric production and has stimulated two radically new patented conceptions, namely: 1) the use of nonwoven fabrics for a short-cut high-speed yarn making method and 2) the development of nonwoven fabrics constructed from yarns, instead of fibers, as is the case in conventional nonwovens.

NEW YARN MAKING SYSTEM

Basically this new process starts where present nonwoven production ends, thus with a nonwoven fabric. To make it suitable for this process, the axial strength of the nonwoven used is of primary importance. For this reason it is mandatory that the staple fibers in such nonwovens be in even, close and substantially parallel arrangement. This basic condition eliminates the use of all nonwoven fabric production methods in which the webs formed are comprised of random or crosswise arranged fibers. Conversely, all the dry or wet web forming methods yielding parallel fiber arrangement are applicable. The choice and the preference of any one method will be governed by the fiber and binder used and the basic performance properties of the yarn called for in the end use product.

The traditional steps of the conventional systems in the "sliver to yarn" stage, which were discussed earlier, are the complex slow and costly multi-

stage sliver drafting, roving and draft-spinning operations. In this process of yarn-making all these steps are completely by-passed (13).

Suitable nonwovens, produced by any preferred web forming technique, are subjected to lengthwise slitting immediately after formation, into a plurality of 1 to 2 inches wide continuous tapes. These tapes are then fed either directly into a patented, novel, multi-spindle yarn making machine or to a winder, to form large traversely wound supply bales of tape of 50-100 pounds or more in weight.

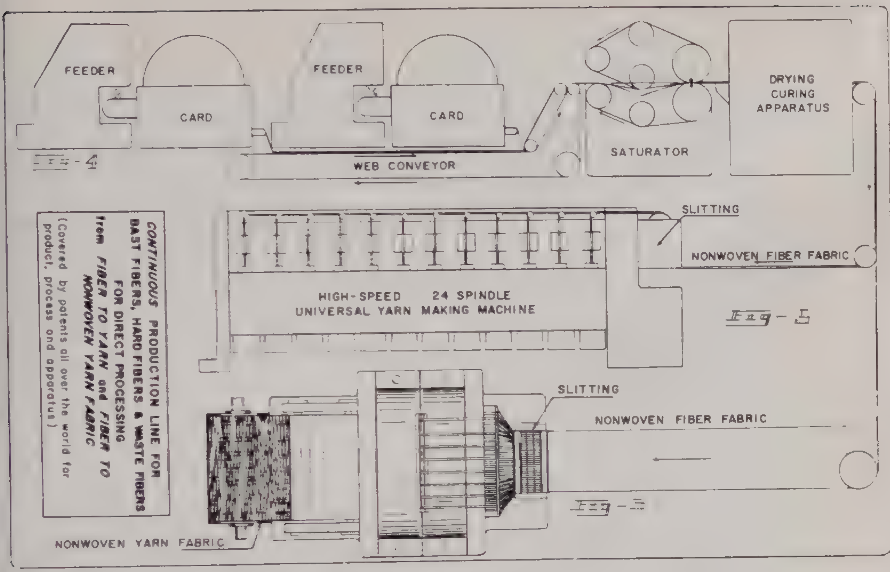
A standard yarn-making machine of the new type is comprised of a plurality of self-contained yarn-making units which eliminate all the drawbacks of conventional spinning. Covered by patents, these small units form the yarn, with any desired amount of positive twist, utilizing a radically different concept hitherto unused for this purpose, without the use of travelers, spinning rings and without the need for any spools whatsoever. The yarn is formed in a straight axial line, hence without ballooning.

Each such standard machine incorporates a slitting device which slits the 1 to 2 inches wide tape fed into it. This tape may be supplied either directly from the nonwoven fabric forming machine or from a large tape supply roll or bale. The tape is slit into a desired plurality of narrow ribbons of any preferred width within a range of 1/64 to 1/4 inch which are in turn individually guided to an equal number of yard forming, twist imparting and yarn collecting devices. Each yarn-making unit incorporates means for heat sealing, twist imparting, traverse yarn package build up, pneumatic yarn transport, yarn collecting and automatic dothng. Each such set up is in the form of a fully integrated, compact yarn making unit, which can be mounted on any frame equipped with the proper driving means. The amount of twist imparted per inch can be simply set and controlled for all the units by turning but one central dial. There are in addition similar dials, one for heat control and the other for delivery speed regulation. The yarn count is primarily governed by the width, weight and density of the input tapes.

Tapes of any type of fibers, their blends and binding agents can be processed on this "universal" yarn-making equipment. It is claimed that it can be used to make yarns from conventional rovings as well. Apparently such yarn-making units can also be mounted onto any conventional spinning machine and can take over the function of conventional spindles to produce any type of conventional yarn desired with much better results, performance and considerably more economically than was hitherto possible.

An added advantage, and as it may turn out, an important one, of this universal yarn-making apparatus is that it is also equipped to produce either zero twist, any positive twist or heat set stretch twist yarns in one operation. The latter is only possible if the tape or roving contains a thermoplastic agent which is suitable for the heat setting technique. Choice of producing any of these yarns is easily available to the spinner by means of a single setting. The yarn packages produced may have a weight ranging from 1 to 6 pounds. The twisting speed ranges up to 15,000 r.p.m. and with additional refinements, possibly up to 20,000 r.p.m. or even higher.

A pilot plant set up, including the universal twister, has been in operation for some time in North America and as claimed, the results are very satisfactory. The yarns made are superior in strength, evenness and appearance, to comparable conventional standard yarns. The results of this development and research work are as yet kept under wraps. However, it is



Figs. 4, 5, and 6.

expected that very soon a wide range of yarns made by this process will be available to a number of North American weavers for proper evaluation.

Apparently a wide variety of yarns can be tailor made by this method to meet the needs and fill the requirements of desirable functional charactistics and performance properties. In appearance, the yarn can be made to look the same as or quite different from comparable conventional yarns. The properties added to the yarn by the imparted bonding agent will constitute an additional asset qualitywise and in most cases, pricewise as well.

As was mentioned earlier, it seems that this process is particularly adaptable for use with the automatic and continuous "fiber to sliver" production set up of the cotton system. By adding to this line suitable web bonding equipment followed by the novel yarn-making machine, an entirely continuous and automatic "fiber to yarn" process could soon become a reality. Such a process is schematically illustrated in Figures 4, 5 and 6. The further inclusion in this system of the high output Duo-Card instead of the slow conventional cards could make this process without doubt the most advanced and economical "fiber to yarn" processing production line hitherto known.

A similar automatic and continuous production line from "fiber to yarn" also holds great merits for bast and leaf fiber processing, because of the use in their processing of cards with much higher outputs and speed ranges. Outputs of 300 pounds or more per hour, per card, are common.

This now possible short cut "fiber to yarn" production process apparently offers considerable savings in space and equipment as well as substantially reduced production costs. Based upon already achieved results it is expected that this new "fiber to yarn" process will have a great impact on the textile markets all over the world, with serious implications.

NONWOVEN YARN FABRICS

A totally novel development is the production of nonwovens using yarns, instead of individual fibers, as the construction material. Method, apparatus and product being patented (49), formation of a unique fabric is claimed. This fabric is comprised of one or more weft and warp layers of yarns arranged in a staggered relationship with respect to each other in the weft and warp layers respectively. When pressed together, this arrangement of juxtaposed warp and weft yarn layers, forces individual yarns to penetrate the interstices between adjoining yarns. Simultaneously applied heat then locks these yarns into place, with the aid of the previously imparted bonding agent. The resulting material is a *nonwoven yarn fabric* having substantially, the construction, appearance, dimensional stability, strength, breeze and hand, of conventional woven fabrics of *inter*laced yarns as is illustrated in Figure 7.

In production of this fabric, the weft yarns may be laid either at right angles or at slightly helical angles to the warp yarn. The latter arrangement is advantageous in that it permits helical winding as a method of continuously depositing the weft yarn layers around the warp layer. It, besides, makes possible much higher production speeds and imparts better dimensional stability to the fabric. Illustrations of this aspect are presented in Figures 8 and 9.

The bonding agent used in this process may be applied in a number of ways. It may be present either in one or both of the yarns used, i.e. weft and warp, or it may be applied to the yarns directly on the web-forming machine before the bonding action takes place.

Any type of yarn can find application in this nonwoven fabric. As in conventional woven materials, the intended end use of the fabric will govern the choice of yarn as well as the choice of any of a multitude of weaves possible. A wide range of weave constructions and patterns is possible, depending on the density of warps and wefts, their arrangement, color, as well as types of warps and wefts used.

The most striking and important feature of this new development is the total elimination of the biggest, as well as, the oldest headache and bottleneck of conventional weaving, namely: *interlacing*. This is even more notable when one considers that, apparently, the same product is obtained by this method as is produced on the conventional loom. Considerably higher speeds of production are possible. A high speed web forming machine of this type is presently in the final design stage in North America. Production rates of about 1,000 yards of standard 12 x 40 jute Burlap per hour are claimed as exemplary. Burlap is an item which is imported to North America in large quantities (about 1 billion yards annually) from India and Pakistan. Because of abundant cheap labor for fiber production and processing, these countries hold a virtual world monopoly in this economically very important material.

According to claims made, this fully automatic process and machine will be in a position to offer successful competition to these imports. It will be particularly effective in competition with imports of all types of cheap packaging materials, carpet backings, upholstery and many other items where performance and low unit price are primary considerations. Besides, it is claimed to be very suitable for the production of reinforced paper laminates, in flat as well as in tubular form, for a wide range of end uses.

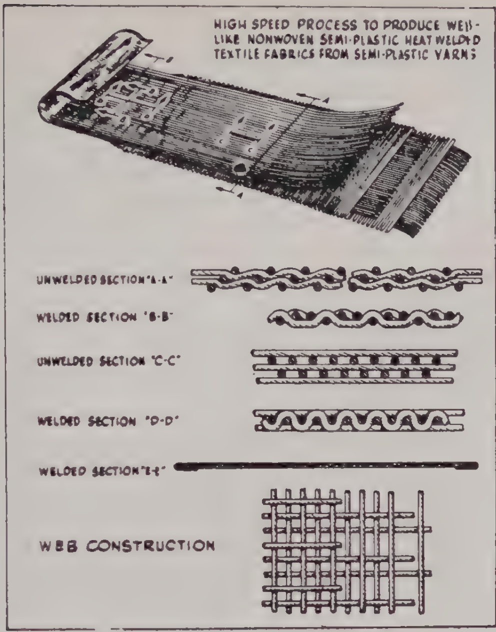


Fig-7

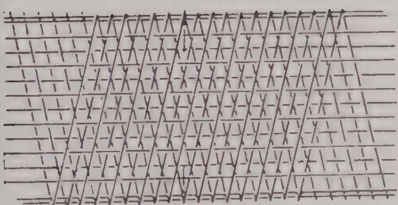


Fig-8

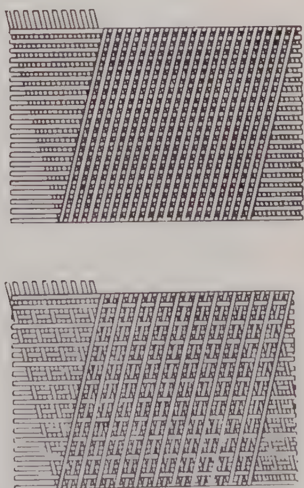


Fig-9

Figs. 7, 8, and 9.

Utilizing nonwoven fabric, zero twist yarns as warp yarns in this system, which would even improve the bonding results, a hitherto only dreamed of continuous, automatic *"fiber to fabric"* production line would become quite feasible, as shown in Figure 6. However, incorporation of a separate weft yarn manufacturing set up would also be necessary. This is illustrated in Figure 5.

With further tests and subsequent refinements of this system, it is believed that heavy inroads into many other markets of conventional weaves can be envisioned as being a certainty.

SUMMARY

Although this is a technical paper, it is well to analyze some of the basic economic factors which have, and always will have, an important bearing on the trends in textile fiber processing, which in turn stem directly from technological research and development activities.

There are three basic factors which determine the success of any textile product: **APPEAL, PERFORMANCE and PRICE.**

It is generally conceded by the textile trade, that, in items in which appeal is the primary consideration, present type nonwovens are less likely to succeed against conventional textile fabrics. They require special production facilities, operated by manufacturers with extensive experience and know-how, as well as highly skilled and diversified promotional marketing set ups. This large group is primarily made up of apparel and some household items.

In the huge industrial, and to some extent household, sanitary and military end use markets, performance and price are of major importance. It has been estimated, that industrial applications take up about 60% of the nonwoven fabric production (50). In items where performance is the prime goal, price considerations are usually of lesser importance. This is a promising field, and one in which nonwovens can make inroads against competition from conventional textiles.

To attain volume consumption in items where price is the deciding factor, as is the case in the packaging materials market, nonwovens will have to sell at a cost below that of woven goods. This will necessitate low cost, large scale production, as well as the use of inexpensive binders and fibers which are cheaper than the costly synthetics. This constitutes an uphill fight, with its successful outcome depending to a large degree, upon further improvements in equipment and processing techniques, as well as on concentrating all efforts on a few selected large volume items.

The effect of nonwoven fabrics on the textile industry as a whole, primarily because of the above mentioned considerations, has been negligible up to now, with a production level of about 100,000,000 pounds in 1959, thus only about 1.5% of the estimated annual fiber consumption of 7.5 billion pounds in North America. It has been predicted, however, that the production of nonwovens in the U.S. will double every three years. A leading Russian textile expert predicts Russian annual production of nonwovens to exceed 200 million yards by 1965. Activity is also strong in Europe, which has fifteen plants in operation, with England and West Germany in the lead. Latin America joined the club with two plants, Japan with three plants and South Africa and Australia with one plant each.

The concensus of opinion among industry observers appears to be that

the present type nonwovens will eat into some borderline woven textile and paper markets, without seriously hurting either industry.

Nine leading U. S. textile men, responding to a recent interview by the Textile World magazine (3), identify the problems of the textile industry by stating that radically new methods of processing fibers into textiles are needed. They went on to say that the number one need of the textile industry is a series of breakthroughs in machinery, and complete elimination of some of the traditional manufacturing steps to meet the mounting competition that natural fibers face from nonwovens, plastics, paper and from continuous filament manmade fibers which require fewer processing stages than do staple fibers.

Enthusiasm of nonwoven optimists is apparently being somewhat dampened, because they realized that a really accelerated growth of nonwovens production can only result from technological breakthroughs in production methods and from approaches which are entirely new in concept. It is quite possible that some of the new developments introduced in this paper will either constitute or lead to just such breakthroughs.

The paper industry is poising itself to lend a hand that may well push nonwoven fabrics into the main stream of existing textile markets, and even invent some new ones.

Dr. Lincoln R. Thiesmeyer, president of the Pulp and Paper Research Institute of Canada, speaking at a recent annual meeting of the Textile Research Institute in New York (51), expressed his belief that the interests of the textile and paper industries are overlapping more than ever, with an accelerated trend towards "marriages" to bring together the technical know-how of each party for the exploitation of the market for the benefit of both. Dr. Thiesmeyer believes that inroads on the textile industry by paper manufacturers, will be very substantial if their new products, through improvement, reach a degree of wide acceptability of the market. Dr. Thiesmeyer commented further that it seemed unlikely that major cost reductions would come about through minor variation of existing practices and equipment. Instead, he declared, they will result from the development of entirely new processes, equipment and approaches.

Adaptation of papermaking technology to equipment modified for handling random laid nonwovens, which are comprised mainly of synthetic fibers, has resulted in continuous production systems and speeds approaching 1,000 feet per minute, becoming a reality in the U.S.. The current maximum speed of the discontinuous multistage dry process on traditional textile machinery used to produce nonwovens is about 40 feet per minute (52).

The prospect of turning out textile-like nonwovens at the speeds of papermaking equipment has created considerable excitement and undoubtedly with much justification, as has been observed by Dr. K. Fox (32). He adds, however, that efficient operation and high speeds mean, logically enough, that there must be sizeable markets. Here an important point is raised, for in fact while the greater production rates of the wet paper process over the dry textile process have a considerably more favorable fiber to fabric conversion cost, a marketing problem does exist because of the high production rate. A medium size (120 inches trim) nonwoven fabric machine of the wet paper type, operating on the lower end of its speed range, would have a rated capacity of about 80 million pounds per year (40), which almost equals the total annual production of all the nonwoven types of fabrics produced last year in the U. S.

A sufficiently large volume market for a few standard types of non-nonwovens would thus be needed to make their production on the high output paper machines economical. It seems less likely that this can be achieved at the present state of inadequately developed markets for *end use* nonwovens. It should be borne in mind that marketing of end use nonwovens will require know-how of dyeing and finishing techniques, extensive promotional work, wide diversification and easy adaptability of the products and styles to ever changing trends before they will become acceptable to the market in large enough volumes to make the wet paper process profitable and feasible. In view of this, some experts express their doubts whether the wet paper process will ever become a successor to the textile system of making end use nonwoven items.

Against such statements can be held the fact that interlining, produced on paper machines, apparently is making heavy inroads into the large traditional textile interlining market because of its superior performance and properties, in spite of its higher price. This success of nonwovens in interlinings, however, could just go to prove one very important point, namely that nonwoven fabric production by the wet paper process perhaps should not be geared to manufacture end use items, with all its ramifications, and should instead, whenever possible, concentrate on the production of inexpensive standard semi-raw materials. These, in turn, could find ready and really large volume markets through the production facilities and marketing channels of the traditional textile industry.

It is by now, an established fact that with the aid of fibrids and other recently developed binders light weight nonwovens, even as light as ½ ounce per square yard, with excellent and desirable properties, can be successfully produced at speeds of up to 1,000 feet per minute. Moreover, paper manufacturers seem to have little doubt, that with further improvements, the use of staple fibers as long as 1 inch will become possible in the wet paper process for making nonwovens.

It has also been recently proven that nonwovens, with substantially parallel arranged staple fibers produced by the *dry* textile process, can be successfully processed into a wide range of yarns. This is accomplished by slitting the nonwovens into narrow tapes and subjecting these tapes to twisting. The resulting yarns possess most of the desirable properties and characteristics of comparable conventional yarns.

From the above one could draw the conclusion, that if the advantages of the high speed nonwoven paper process utilizing textile length fibers, could also be adapted to produce nonwovens having substantially parallel arranged staple fibers, suitable for use as a basic semi-raw material in the novel yarn-making process, the long awaited revolutionary breakthrough in textile fiber processing into yarns and subsequent fabrics, could become a reality.

It seems that the most effective way to tackle this complex problem, would be through an aggressive and concentrated research and development effort, possibly carried out under the auspices of a research institute properly equipped for the task. The writer believes that with certain modifications and development work, nonwoven fabrics of substantially parallel arranged staple fibers can be turned out on papermaking equipment at rates approaching papermaking speeds. This belief is further supported by the changing face of the papermaking mills. Latest developments in equipment and processing methods illustrate the vitality and versatility of this industry.

Existence of such a process would move a 7.5 billion pounds annual yarn market in North America to within reaching distance of the paper industry. This would probably constitute the *greatest chance and challenge* ever faced by the paper industry. It is conceivable that well over 50% of all the cotton yarns used by the textile industry could well be produced by the novel yarn-making method from non-wovens manufactured by the high speed wet paper process. The savings in processing costs would be enormous.

The ultimate benefits to mankind and savings to the economy of the whole world resulting from such savings in processing of all types of textile fibers are difficult to envisage. A reduction, for instance, of only 5% of the estimated $20 billion cost to U.S. consumers of cotton textiles alone, would result in the saving of about $1 billion annually.

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CONTRIBUTED PAPERS AND PANEL DISCUSSION

W. K. ROBERTSON, *Presiding*

Responses of Clover Varieties to Minor Element Fertilization at the Suwannee Valley Station[1]

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INTRODUCTION

A satisfactory winter legume is not grown, at present, in the Suwannee Valley area. Bitter blue and sweet lupines are no longer economical as cover crops in this area because severe virus disease incidence causes crop failures. Although most of the farm land is considered too dry for clover growth, there are soils that can be used for clover pasture. Very little information is available on the variety of clover best suited for the area or the fertilization required. The present studies were undertaken to provide data on the requirements for minor elements of several clovers on soils limed and otherwise amply fertilized.

LITERATURE REVIEW

The sandy soils in the Suwannee Valley area are often deficient in magnesium and respond to lime, as reported by Blue and Eno (1). They consistently found magnesium deficiency symptoms in forage plants grown on Jonesville and Klej fine sands. Although magnesium sulfate applications corrected deficiency symptoms and increased yields, they found that leaching occurred when this source was used and recommended dolomite be used instead of the sulfate. In their work, leguminous green manure crops promoted higher magnesium levels in crops that followed. Gammon and co-workers (6) stated that the use of minor elements in fertilizing pasture soils is cheap insurance and may make or save a crop. Their experience with clovers was that boron and copper are more frequently deficient in soils suited to clover than are manganese, molybdenum, iron, and zinc. They pointed out that minor element fertilization need not be frequent, nor at high rates and that mineral supplements fed to cattle eventually contribute to the supply available to pasture plants.

Details for production and management of clover pastures were reported by Hodges, Jones, and Kirk (8). They stressed the need for liming to provide at least 1200 pounds of calcium per acre in the soil, and for 500 pounds per acre of 0-12-12 at planting followed by 250 pounds of 0-8-24 in February. They stated that minor elements should be applied for new plantings and after four or five years. Five years of results using eight pasture programs at the Beef Research Unit have been reported (8).

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Using white clover on land uniformly limed treated with minor elements and fertilized with 600 pounds per acre of 0-12-12 prior to planting and annually in October, the data showed white clover-grass pastures produced beef at 60 percent of the cost for all-grass pastures. In this area, white clover survival during the summer has steadily increased. Marshall (10) reported that white clover grown on Scranton loamy fine sand provided the principal forage for dairy heifers from February to May and its feed replacement value averaged 98 dollars per acre.

Nitrogen produced by good clover growth has proven to be sufficient for summer grass pastures (2, 4, 7). The recovery of 220 pounds per acre of nitrogen in clover-bahiagrass pastures reported by Gammon *et al.* (7) compared favorably with the 3-year average of 303 pounds of total nitrogen from white clover-pangolagrass on clipped plots obtained by Fiskell (4). These experiments were both conducted without addition of nitrogen in the fertilizer.

MATERIALS AND METHODS

Materials. The dolomitic and calcitic limestone used in the experiments were standard agricultural grade. The 0-14-14 and 0-10-20 fertilizers were commercial formulations derived from superphosphate and muriate of potash. The minor element sources used singly were reagent grade copper sulfate, zinc sulfate, sodium molybdate and the finely ground fritted boron source termed 176F or Saftebor which contained 19 percent B_2O_3. Two minor element mixtures with slow to moderate rates of release of the metals were tested. The complete fritted source, FTE 501, was a finely ground product with the guaranteed analysis: 6.5 percent B_2O_3, 2.5 percent CuO, 5.0 percent ZnO, 6.3 percent MnO, 17.3 percent Fe_2O_3, and 0.2 percent MoO_3. The other minor element mixture with the trade name MEM used in Rainbow Brand of fertilizer contained water insoluble sources of the metals, chelating agent and the 176F frit. The fertilizer with the MEM incorporated contained the following elements expressed as the oxides in pounds per ton: 19 of Fe_2O_3, 12 of MnO, 6.7 of ZnO, 3.3 of CuO, 4.3 of B_2O_3, 3.0 of BaO, 1.3 of SrO, and lesser amounts of 10 other elements. Clover seed and the inocculum were obtained locally.

Soil. The area chosen for the experiments had not been previously cropped for many years. While surface water drains freely from the area, the soil is classified as wetter than the nearby Klej and Jonesville fine sand. The soil is primarily Blanton fine sand with some smaller areas of Scranton fine sand. The original pH is 5.0 with 38 to 50 pounds of Ca per acre in the top 6-inches.

Methods. The area was turned and disked during August and September. The dolomite was applied in early October at the rate of one ton per acre and disked into the top 4 to 5 inches. Plots 10 feet by 20 feet were laid out leaving an alley 5 feet wide around each six plots. Six treatments were applied in each such area. The materials were mixed in 0-10-20 and broadcast over the plot. Fertilizer rate was 1000 pounds per acre and rates for the minor element treatments were as follows: Copper sulfate and frit 176F at 10 pounds per acre, zinc sulfate at 20 pounds per acre, sodium molybdate at 4 ounces per acre, and frit 501 at 30 pounds per acre. The experiment consisted of 6 treatments for 6 clover varieties replicated

three times. After fertilization, the soil was disked to a depth of 3 to 4 inches prior to seeding. Crimson, Hubam, Ladino, White Dutch, and Nolin's white clovers, and Peruvian alfalfa were sown on November 4, 1958. Varieties grew as pure stands within the treated areas. Yields were taken using a central swath from each plot. After weighing, samples were put in polyethylene bags for moisture and chemical analysis. This area was fertilized with 110 pounds of muriate of potash in the fall of 1959 and 1960.

On adjacent soil, a second experiment was begun in the fall of 1959. Dolomitic lime was broadcast over this area at the rate of one ton per acre. This was rotatilled to a depth of 6 inches. To study the effect of fritted minors in lime, one-half ton of calcitic lime with and without 30 lbs. of frit 501 was spread in paralled strips 20 feet wide down the field leaving such a strip with dolomite only. These three treatments were randomized in four replications. The lime and fertilizer were spread by an Easy-Flo distributor. Five hundred pounds of 0-10-20 fertilizer with and without the MEM source of minor elements was spread in similar strips vertically across the limed area. In mid-October, Kenland red, Ladino, Crimson, and Nolin's white clover were sown over the fertilized strips. The seed was put out by hand and rolled in with a cultipacker. Yields were taken from an area 6½ feet by 20 feet and samples were saved for analysis. Chemical analyses were run by methods previously reported (5).

RESULTS AND DISCUSSION

The clover varieties that produced the best growth were Crimson, Hubam and both Nolin's and White Dutch clover. Ladino was very irregular in the plots. The Peruvian alfalfa stand was excellent but the plants were spindly and the leaves slightly chlorotic. In the second experiment, Crimson and Ladino showed more even growth than did the Kenland red or Nolin's white clover. In all cases, the clovers did not survive where seed fell on unlimed or unfertilized soil in border areas. Soils in this area are too low in fertility for clover growth unless they are limed and fertilized properly. As shown in subsequent data there is also a need for minor element additions at the same time that lime and fertilizer are applied.

In Table 1, data are shown for the 6 varieties planted in 1958. All were harvested on April 12, 1959 and a second cutting of Nolin's, White Dutch and Ladino clover was taken on May 26. Analysis of variance for the yields taken in the first cutting showed highly significant differences between varieties. By Duncan's new multiple range test (3), Hubam yielded the highest. The Crimson, Nolin's and White Dutch clovers yielded alike and were much superior to Ladino clover or Peruvian alfalfa. There was a highly significant increase in yield where either frit 176F or 501 was added but not for the other treatments. The chemical analysis showed much higher boron in the plant where the frits were applied. Since the content of other elements in the plants appears adequate from the analysis and since boron level of 20 parts per million in clovers is low, the yield response was attributed to the boron supplied by the frit. Visual differences in height of Hubam and in poorer seed formation where boron was not added, were not reflected in the yields. The second clipping data were analyzed and showed the three varieties yielded alike. Treatment effects

TABLE 1.—GREEN WEIGHT YIELDS OF CLOVER VARIETIES AND THEIR MINERAL COMPOSITION FROM PLOTS RECEIVING SEVERAL MINOR ELEMENT TREATMENTS.

	Minor Element Treatments						
Factor measured	None	Copper sulfate 10 lb/A	Zinc sulfate 20 lb/A	Sodium moly. ¼ lb/A	Boron frit 176F 10 lb/A	Complete frit 501 30 lb/A	L.S.D.
Crimson clover (21 ± 2% dry weight)							
Yield, 4-12-59	11,000	13,100	11,200	11,400	16,800	17,200	2,200
Boron, ppm. B	17	20	16	19	35	30	7
Manganese, ppm. Mn	120	140	112	110	85	83	N.S.
Iron, ppm. Fe	96	74	100	82	73	68	N.S.
Aluminum, ppm. Al	162	94	175	141	74	85	32
Calcium mgm/gm.	10	12	11	11	11	11	N.S.
Magnesium, mgm/gm.	4.0	4.2	7.6	5.6	5.2	4.0	N.S.
Hubam clover (21.7 ± 1.9% dry weight)							
Yield, 4-12-59	19,700	20,000	20,300	20,300	21,700	21,600	N.S.
Boron, ppm. B	10	14	11	16	32	31	8
Manganese, ppm. Mn	103	85	107	100	92	93	N.S.
Iron, ppm. Fe	63	77	102	107	65	79	N.S.
Aluminum, ppm. Al	72	68	42	77	55	46	20
Calcium, mgm/gm.	9.6	7.5	9.5	11.0	8.8	7.9	N.S.
Magnesium, mgm/gm.	3.8	4.2	7.2	5.6	4.7	3.9	2.4
Peruvian alfalfa (26.3 ± 1.6% dry weight)							
Yield, 4-12-59	4,250	4,340	3,920	4,600	5,230	5,880	610
White Dutch clover (15.3 ± 1.8% dry weight)							
Yield, 4-12-59	14,000	16,800	14,100	14,000	15,500	18,000	1,900
Yield, 5-26-59	4,760	5,980	5,770	5,460	7,070	6,350	510
Boron, ppm. B	19	22	22	18	38	30	6
Manganese, ppm. Mn	138	172	135	130	110	125	N.S.
Iron, ppm. Fe	79	130	126	100	69	98	21
Aluminum, ppm. Al	156	121	173	225	241	63	62
Calcium, mgm/gm.	15.0	12.4	17.5	14.2	16.0	16.9	1.6
Magnesium, mgm/gm.	2.0	2.5	4.4	3.4	3.1	4.1	1.2
Nolin's White clover (15.9 ± 2.1% dry weight)							
Yield, 4-12-59	13,300	15,500	16,500	13,900	18,000	19,900	920
Yield, 5-26-59	4,700	6,000	5,650	5,090	7,720	8,170	630
Boron, ppm. B	21	18	19	20	41	33	6
Manganese, ppm. Mn	75	99	105	125	180	125	31
Iron, ppm. Fe	117	158	110	104	128	122	N.S.
Aluminum, ppm. Al	158	277	267	185	134	121	31
Calcium, mgm/gm.	13.1	14.2	12.1	12.8	13.3	13.5	N.S.
Magnesium, mgm/gm.	2.9	3.4	3.6	3.2	3.6	3.4	N.S.
Ladino clover (15.1 ± 1.5% dry weight)							
Yield, 4-12-59	4,790	4,760	9,320	2,170	9,970	5,270	N.S.
Yield, 5-26-59	5,600	7,070	6,930	4,780	6,770	8,540	2,100
Boron, ppm. B	19	22	21	20	41	33	7

and replications were highly significantly different. By Duncan's test, the frits were the most effective treatments in increasing the yields but both zinc and copper were better than the check or molybdate in this respect. Dry weights of these yields did not alter the above interpretations other than to emphasize the Hubam and Crimson yields.

Effects of the treatments were observed the following year. Only 4 of the varieties, Table 2, reseeded or lived over from the previous year. The three white clovers did survive for 12 months on the plots although growth was curtailed in the summer months. Better seed production and perhaps better vitality of seed where the boron was added, probably account for the much higher yields on these plots. Residual boron in the soil apparently increased the yields similar to the boron response of the previous year. The Ladino clover showed a response to copper, molybdate and frit 501 but not to frit 176F. The same was true for the Nolin's white. Possible explanation is that the more soluble 176F was leached to an insufficient level of boron whereas the 501 frit persisted longer. White Dutch clover yielded better where zinc or frit 501 was applied than where copper or boron frit 176F was added and the latter were better than the check. Persistence of the boron effects from the frit 501 accounted for yields twice those of the check plots. Inroads of weeds and grasses during the summer of 1960 prevented yield evaluation of clover still persisting on some of these plots. However, no treatment effect was found in the Crimson clover harvested May 5, 1961 and which averaged 1150 pounds of green weight per acre. Possibly the over-all fertility of the soil had declined below the level for proper growth.

TABLE 2.—YIELDS OF CLOVER VARIETIES IN 1960 THAT RESEEDED OR LIVED OVER FROM THE PLOTS PLANTED AND FERTILIZED IN 1958.
(lbs per acre of oven-dry weight, average of 3 replications)

		Minor elements added in 1000 lb. 0-10-20, in 1958					
Variety	None	Copper sulfate 10 lb/A	Zinc sulfate 20 lb/A	Sodium moly. ¼ lb/A	Boron 10 lb/A frit 176F	Complete frit 501 30 lb/A	L.S.D.
Crimson clover	790	1,560	1,200	1,070	2,970	3,040	750
Ladino clover	1,660	2,550	2,170	2,450	2,010	2,770	580
Nolin's W. clover	1,180	2,030	1,550	2,040	1,730	2,430	850
W. Dutch clover	1,350	1,790	2,320	1,630	1,840	2,290	390
Average	1,220	1,980	1,810	1,800	2,140	2,630	

In the second experimental area, the comparison between minor elements added in the fertilizer or in the lime was conducted over a two-year period. Although the soil was uniformly fertilized and limed with dolomite, treatment differences showed both a need for additional lime and for minor elements. In Table 3, the data showed Crimson clover responded greatly to the calcitic limestone the first year and to a lesser degree the second year. Lime with frit 501 also was highly significantly effective in increasing the yields both years. Where minor elements were added in the fertilizer, yields were increased both years at both lime levels. Having minor elements both in the lime and in the fertilizer did not increase yields beyond that for extra lime with the fertilizer containing the MEM mixture. Apparently the frit 501 and MEM source have about the same residual effect and when combined did not further increase the Crimson clover yield. The 1961 growth was from clover that reseeded. The yields of Nolin's white clover also showed the need for more lime the first year but not as significant a difference occurred the second year. The 501

TABLE 3.—YIELDS OF CRIMSON AND NOLIN'S WHITE CLOVER WITH AND WITHOUT SLOWLY SOLUBLE MINOR ELEMENT MIXTURES WHICH WERE APPLIED EITHER IN THE FERTILIZER OR IN LIME ON SOIL OTHERWISE UNIFORMLY TREATED WITH DOLOMITE AND FERTILIZER.
(green weight as pounds per acre, average of 4 replications)

	Treatments in addition to 1 ton of dolomite[1]					
			½ ton calcitic lime		½ ton calcitic lime + 30 lbs. Frit 501	
Year	0-14-14	0-14-14 + M.E.M.	0-14-14	0-14-14 + M.E.M.	0-14-14	0-14-14 + M.E.M.
			Crimson Clover			
1960	2,180	8,080	5,760	12,700	9,760	13,400
1961	6,950	8,420	8,200	10,800	10,800	11,900
Ave.	4,570	8,250	6,980	11,750	9,780	12,650
			Nolin's White Clover			
1960	4,200	4,200	10,400	13,600	13,000	14,400
1961	7,040	9,830	8,140	11,100	10,200	13,200
Ave.	5,560	7,020	9,270	12,350	11,600	13,800

[1]Differences of 1100 pounds for the 1960 yields and 1570 for the 1961 yields of Crimson clover are highly significant.

Differences of 1250 pounds for the 1960 yields and 1600 pounds for the 1961 yields of Nolin's white clover are highly significant. Minor elements were applied only in 1959 prior to planting. See text for description of International's M.E.M. mix and Ferro Corporation's frit 501.

and MEM mixtures were both highly effective in promoting better yields both years and when combined gave higher yields in 1961. Economically, these yield increases were worth more than the cost of the minor element mixtures.

Yields of Kenland red clover that received regular 0-10-20 fertilizer are reported in Table 4. A very significant yield increase was found for both additional lime and lime with frit 501. Yield differences in 1960 were more striking than in 1961 but the responses were similar. This clover reseeded well in the area. Yields approached those of the other varieties in the experiment.

Ladino clover was grown on an adjacent area where the 0-10-20 fertilizer contained the MEM mixture of minor elements. A very significant response to the addition of the calcitic lime occurred in 1960 but not in 1961 and further addition of minor elements from the frit 501 did not affect the yields. This variety, as shown before in Table 1, had a more erratic and somewhat different response pattern to minor elements than the other clover varieties. This was attributed to its greater sensitivity to some unknown soil factor, perhaps soil acidity. The clover on Scranton soil survived the summer months both years whereas somewhat sparse stands occurred in the Blanton soil. Nolin's white clover was much less sensitive to differences in the soil series.

Although very large yield increases occurred from the minor element additions, there were no striking deficiency symptoms in the clover without these minors. There were occasional red leaves in the white clovers indicating boron deficiency but the general pattern of growth on the plots untreated with frit or MEM was stunted plants and somewhat smaller

TABLE 4.—EFFECTS OF ONE-HALF TON OF CALCITIC LIMESTONE WITH AND WITHOUT FRIT 501 ON THE GREEN WEIGHT YIELDS OF KENLAND RED AND LADINO CLOVER ON SOIL UNIFORMLY LIMED WITH ONE TON OF DOLOMITE AND UNIFORMLY FERTILIZED.

	Treatments				F Value	
Year	Dolomite	Calc. lime plus dol. limestone	Calc. lime with frit 501 + dol. limestone	L.S.D.	Treat.	Reps.
	lb/A	lb/A	lb/A	lb/A		
			Kenland Red Clover[1]			
1960	3,800	7,800	10,600	1,200	16.31[2]	1.65
1961	7,230	9,190	10,140	550	13.58[3]	.45
Ave.	5,560	8,500	10,370			
			Ladino Clover[2]			
1960	3,600	7,000	6,400	860	9.76[3]	2.69
1961	14,200	15,300	16,100	N.S.	.59	7.30[4]
Ave.	8,900	11,100	11,200			

[1]Fertilized with 500 lbs. of regular 0-14-14 at planting in 1959 and 100 lbs. of muriate of potash in October of 1960.
[2]Fertilized with 500 lbs. of 0-14-14 containing the MEM mixture at planting in 1959 and 100 lbs. of muriate of potash in 1960.
[3]Significant at the 1 percent level.
[4]Significant at the 5 percent level.

leaves. There would be no way to recognize in the field whether or not minor elements were needed unless it was known from past experiences. This uncertainty and the relatively low cost of adding minor element mixtures in the fertilizer, makes it good policy to include them as insurance.

CONCLUSIONS

Crimson clover and Kenland red clover grow well on soils such as Blanton and Scranton fine sands provided proper liming and fertilization are used. High calcic limestone and dolomitic limestone may be required. The 0-14-14 or 0-10-20 fertilizer should contain minor elements, preferably slowly soluble boron frits so that boron availability is maintained during the year. Alternatively, commercially available calcitic limestone containing frit 501 is as acceptable as having the minor elements in the fertilizer. In these tests, the two above varieties reseeded well. Hubam did excellently the year it was planted but did not establish well the second year. This variety sown annually was the highest yielding and had the least need for addition of minor elements.

Live-over of Nolin's, White Dutch and Ladino clovers was observed all three years which was surprising because several summer droughts occurred. These varieties also were sensitive to proper liming and responded well to the slowly soluble minor element mixtures applied either in the lime or in the fertilizer.

These studies showed that several clover varieties could be grown in the Suwannee Valley soils that are not too droughty. A recent Soil Survey of Suwannee County showed that there were 31,000 acres of soil types that

are similar in moisture holding properties to those where these experiments were conducted. Details of maintenance and of pasture management have been worked out on somewhat similar soils in the State and have been referred to in the literature review. The addition of minor elements in clover fertilization in this area, resulted in large yield increases and provided a better chance for a successful crop.

ACKNOWLEDGMENT

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The Effect of Seasonal Variation on Soil Reaction and Nutrient Status of Some Western Florida Soils[1]

M. C. LUTRICK[2]

Sampling soils throughout the year is necessary in a well organized plan of research and in routine soil testing where laboratory facilities are to be used most efficiently. Most investigators recognize the importance of obtaining representative soil samples of the particular plots sampled. Frequently, after good soil samples have been obtained, other factors are sometimes overlooked.

Several factors affect the results and interpretation of the chemical analyses of soils. Probably, one of the most important factors to consider is seasonal variation. This is true because temperature, rainfall, evaporation, soil type and crop grown affect the results of chemical analyses of the soil.

In this preliminary study, samples were taken monthly from virgin and cultivated areas of three soil series. Analyses of these samples were made to determine seasonal variation of soil reaction and nutrient status.

REVIEW OF LITERATURE

The influence of season on the availability of plant nutrients and certain soil properties has been studied by many investigators. It was pointed out by Kerr and Von Stieglety (6) that soil sampling should be done just prior to or immediately following harvest time. When a project is to extend over a period of years, the above authors suggest that the time of sampling should come at a definite point in the cropping cycle. On the other hand, Lunt *et al* (7) reported that samples taken in early spring gave the best results.

Anthony[3] found in his study of seasonal variation that there was significant variation of soil reaction in the soils examined. In three out of four soils examined for available potassium, there were differences attributed to seasonal variation. Variations in calcium were not detected in any of the soils, while only two had variations in available phosphorus. There were variations in exchangeable potassium in Eustis loamy fine sand that could be attributed only to seasonal variation according to Lutrick (8).

Bell and Thornton (1) reported that there was no consistent change in pH with season and no significant influence on the pH of soil to fertilizer. Available phosphorus and potassium were significantly increased by fertilizer additions and both decreased as the season progressed. The same results were obtained by Thornton *et al* (11). They also noted that from month to month the results were quite variable, amounting to as much as one hundred percent.

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[3]Anthony, W. H. Seasonal changes and errors involved in sampling and laboratory procedure in the evaluation of soil fertility. Unpub. M.S. thesis, Louisiana State University, Baton Rouge, La. 1949.

Carolus and Lucas (3) in studying factors influencing fluctuation in acidity, reported that leaching caused an increase in acidity. They also found that high fertility tends to increase acidity by salt formations from evaporation. It was pointed out by Huberty and Haas (5) that, under irrigated conditions, there was no net yearly change in pH although the pH was highest in midsummer. The above authors also found that rainfall, in the amount equal to that of a normal year, had no effect on the pH of the soil.

When considering productivity as related to seasonal variation, Thornthwaite (10) stated that the most significant factor was the relation of precipitation to evaporation. He pointed out that its effect was direct and positive and may well be of such magnitude as to mask seasonal variations of productivity due to actual fertility variations.

In summarizing the data presented by these research workers, it follows that soil reaction and the amount of available plant nutrients, as determined by laboratory methods, depends upon the seasonal time of sampling.

METHODS

Samples were taken monthly of virgin and cultivated soils of Americus, Ruston and Norfolk series. Each sample consisted of six cores taken on a 10 foot square area. Calcium and potassium were extracted from the soil using neutral normal ammonium acetate according to the method of Schollenberger and Simon (9). The model B Beckman Spectrophotometer with the flame attachment was used for the calcium and potassium determinations.

Phosphorus was extracted with 0.1N HCl and 0.3N NH_4F according to Bray and Kurtz (2) and determined colorimetrically according to Fiske and Subborrow (4).

Samples having a soil-water ratio of 1:1.5 were allowed to stand for one hour and then the pH was determined using a Beckman pH meter.

RESULTS AND DISCUSSION

The total amount of rainfall measured at the West Florida Experibent Station for the period of this study was more than the average anticipated rainfall of 60 inches per year (Table 1). Even with the excessive rainfall, there were periods of very dry weather which is typical of Western Florida. During these very dry periods, sampling the soil was more difficult and probably resulted in a greater sampling error.

The soil temperature increased gradually from February to July at which point it began to decline (Table 2). The average increase in soil temperature from winter to summer is about 30° F. This increase results in a tremendous increase in the chemical and biological activity in the soil. The amount and distribution of rainfall, along with the changes in the soil temperature, are believed to be the major factors affecting soil reaction and the nutrient status of the soils on a seasonal basis.

The additions of fertilizer to the cultivated plots in this study were made prior to the beginning of the experiment; therefore, any differences in analyses are not the direct result of fertilizer applications.

TABLE 1.—RAINFALL DATA AT THE WEST FLORIDA EXPERIMENT STATION.

Period	1-7	8-14	15-21	22-31	Total
	Rainfall in Inches				
February, 1960	2.14	0.74	0.73	1.37	4.98
March	0.97	0.00	2.85	2.19	6.01
April	8.22	0.35	0.00	0.01	8.58
May	3.11	1.07	0.00	0.81	4.99
June	0.04	0.51	0.91	0.87	2.33
July	1.16	2.45	1.39	0.46	5.46
August	1.61	2.22	1.57	2.40	8.10
September	0.97	1.60	12.94	0.85	16.36
October	3.15	0.30	0.93	0.70	5.08
November	0.00	0.24	0.04	1.98	2.26
December	0.00	0.43	1.85	2.53	4.81
January, 1961	0.11	0.95	0.18	2.56	3.81
				Total	72.77

The variations of 0.5 to 0.6 of a pH unit in soil reaction with the season were apparent on all three soil series and of such magnitude as to mask the addition of 3000 to 4000 pounds of lime per acre (Table 3). One ton of limestone per acre was applied to the Americus cultivated soil, and 2 tons per acre were applied to both the Ruston and Norfolk cultivated soils. Therefore, the addition of lime does not eliminate the variations in soil reaction with season. The variation in rainfall distribution as shown in Table 1 does not correspond to the changes in soil reaction with season. The soil reaction is lowest in summer and highest in late winter. By comparing the soil temperature in the month prior to sampling (Table 2) with the soil reaction (Table 3), it may be noted that there is a decrease in soil reaction as the soil temperature increases. It is probable that the increase in soil temperature increases the hydrolysis of aluminum and iron compounds in the soil which liberates more hydrogen ions. This would cause the soil reaction to decrease.

The amounts of potassium extracted from both virgin and cultivated samples of all three soil series were somewhat erratic from month to month.

TABLE 2.—AVERAGE MAXIMUM AND MINIMUM SOIL TEMPERATURE AT TWO INCH DEPTH.

Month	Soil Temperature in Degrees Fahrenheit		
	Maximum	Minimum	Average
February, 1960	56	46	51
March	61	48	55
April	73	61	67
May	77	66	72
June	86	75	81
July	87	79	83
August	85	77	81
September	84	75	80
October	78	68	73
November	69	58	64
December	55	46	51
January, 1961	54	46	50

TABLE 3.—EFFECT OF SEASONAL VARIATION ON SOIL REACTION. 1960-61.

Soil Type	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Americus (V)*	5.4	5.3	5.3	5.2	4.8	4.8	5.0	5.1	5.3	5.2	5.2	5.3
Americus (C)*	5.6	5.6	5.7	5.4	5.2	5.1	5.4	5.4	5.7	5.8	5.6	5.7
Ruston (V)	5.5	5.3	5.3	5.0	4.8	4.7	4.9	4.9	5.3	5.2	5.3	5.3
Ruston (C)	5.7	6.1	5.6	5.3	5.3	5.3	5.5	5.4	5.8	6.0	5.7	5.8
Norfolk (V)	5.2	5.2	5.0	4.9	4.6	4.5	4.8	4.8	5.1	5.1	5.0	5.0
Norfolk (C)	6.0	5.8	5.8	5.6	5.1	5.3	5.6	5.5	5.7	5.7	5.6	5.9

* (V)=Virgin Soil
* (C)=Cultivated Soil

TABLE 4.—EFFECT OF SEASONAL VARIATION ON POTASSIUM. 1960-61.

Soil Type	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
					K_2O—Pounds Per Acre							
Americus (V)*	118	120	103	118	103	103	125	103	96	124	108	132
Americus (C)*	266	247	262	168	310	144	173	173	156	216	142	178
Ruston (V)	110	125	132	98	98	108	125	98	98	106	94	120
Ruston (C)	173	173	175	151	144	144	168	132	144	168	144	137
Norfolk (V)	73	79	60	67	60	74	67	67	67	72	70	61
Norfolk (C)	73	67	74	79	74	60	53	48	47	61	96	84

* (V)=Virgin Soil
* (C)=Cultivated Soil

TABLE 5.—EFFECT OF SEASONAL VARIATION ON PHOSPHORUS. 1960-61.

Soil Type		Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
						P_2O_5—Pounds Per Acre							
Americus	(V)*	23	23	23	23	23	23	23	23	23	23	23	23
Americus	(C)*	195	115	188	80	188	215	185	240	273	298	195	185
Ruston	(V)	23	23	23	23	34	23	23	23	23	23	23	23
Ruston	(C)	135	89	96	89	126	89	78	101	101	119	94	80
Norfolk	(V)	23	16	23	23	39	23	23	23	34	23	23	23
Norfolk	(C)	103	105	366	169	133	96	126	126	69	149	78	124

* (V)=Virgin Soil
* (C)=Cultivated Soil

TABLE 6.—EFFECT OF SEASONAL VARIATION ON CALCIUM. 1960-61.

Soil Type		Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Americus	(V)*	742	644	672	518	518	560	756	560	462	378	490	518
Americus	(C)*	1134	798	1120	952	1036	980	1554	1302	1610	1456	1330	1260
Ruston	(V)	546	490	434	434	448	448	588	462	434	448	420	518
Ruston	(C)	770	1106	812	784	1022	868	938	868	980	1190	896	1010
Norfolk	(V)	280	252	322	350	364	308	420	378	350	366	336	378
Norfolk	(C)	1904	2380	1890	2002	1806	1750	2086	1722	1470	1750	1400	1400

* (V)=Virgin Soil
* (C)=Cultivated Soil

In general, the variations in the amount of potassium were small enough to be within the errors expected in sampling and laboratory analysis (Table 4).

The potassium content of the virgin samples of all three soil series was about the same at the end of the experiment as it was at the beginning. This shows no net loss of potassium from the virgin soils. The amount of potassium extracted from the cultivated soils decreased as time passed. This indicates that a considerable amount of potassium was being used by plants and/or leached through the soil profile. The quantity of potassium lost from the cultivated soils seems to be in proportion to the initial level of the element. In fact, the potassium content of the cultivated Norfolk soil (Table 4), which is low, actually tended to increase at the end of the season. This increase in potassium content brought the level back to where it was originally.

The virgin soils were very low in phosphorus in all cases (Table 5). In the cultivated samples of all soil series, the phosphorus content did not vary consistently with the season. In the cultivated soils of the Americus and Norfolk series, the phosphorus applied in February was not detected for two or three months in the soil samples. This delay was probably due to the poor distribution of phosphate as a result of its slow solubility in the soil. In the Ruston series, no phosphate was added in the area sampled and still some variation occurred. These variations are believed to be within the error of sampling and methodology.

The results of the calcium determination on soil extracts from samples taken monthly are very inconsistent on both virgin and cultivated soils (Table 6). This variation occurs on all three soil series and is greater than the variation encountered in instrumental analysis. The large variation could be due to the difference in calcium content of the soils. The differences probably are not due to seasonal variation because the results are so inconsistent among the soils in relation to the season.

SUMMARY AND CONCLUSION

The exact role that the distribution and quantity of rainfall play in this study is not clear. It seems that alternate wet and dry periods that are typical of Western Florida would affect the results.

The increase in soil temperature from late winter to mid-summer corresponds to a gradual decrease in the soil reaction. The increase in soil temperature evidently increases the chemical and biological activity in the soil which causes a decrease in the soil reaction. This decrease in soil reaction is probably the result of an increase in the hydrolysis of aluminum and iron in the soil.

The only seasonal variation in potassium content of the soil was in the cultivated soils. The potassium content decreased in the cultivated soil with time after fertilizer applications.

There does not seem to be any definite indication that the phosphorus and calcium content varies with the season.

There is a need for a more detailed study of this problem as shown by the data presented. It is evident that soil reaction and potassium content are influenced by season. Therefore, this knowledge should be considered in the interpretation of the results and subsequent fertilizer recommendations.

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Soybean and Wheat Yield Response to Residual Phosphorus, Potash, and Lime for Red Bay Fine Sandy Loam[1]

W. K. ROBERTSON AND C. E. HUTTON[2]

Soybean acreages in Florida have increased from 8,000 in 1951 to 36,000 in 1961. In the same period wheat acreages have increased from 1,000 to 8,000. More than half of these acres are located in North and West Florida. It is the purpose of this paper to report the response of these crops to residual phosphorus, potash, and lime on Red Bay fine sandy loam, a representative soil of West Florida. Data from fertility experiments on soybeans conducted on Norfolk loamy fine sand near Quincy and Ruston fine sandy loam near Marianna have been published in part (4, 8). There have been no published data from West Florida on soybeans and none from Florida on wheat.

METHODS

An experiment was started in 1949 on Red Bay fine sandy loam to test the response of a corn-peanut rotation to nitrogen (0, 15, 30, 60 and 120 lbs. per acre of N), phosphorus (0, 30, 60, 120 and 240 lbs. per acre of P_2O_5), and potassium (0, 15, 30, 60 and 120 lbs. per acre of K_2O) applied annually. A lime variable was introduced using the split plot technique in which one ton per acre of dolomite was applied to the limed half in 1949

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and two tons in 1952. Details of this experiment and some soils and yield data have been reported (3, 5).

In 1957 the fertility treatments listed above were discontinued and the two-year rotation of corn and peanuts was changed to a one-year rotation of soybeans grown in the summer followed by wheat in the fall. Nitrogen was applied uniformly to the wheat at the rate of approximately 60 pounds of nitrogen as ammonium nitrate per acre. No other fertilizer was applied. By following the levels of residual phosphorus, potassium, calcium, and magnesium in the soil and correlating these values with the yield data, the growth responses of soybeans and wheat to the residual levels of these elements could be obtained.

Soil samples from the 0-6 inch depth were taken annually following wheat harvest and preceding the soybean planting. In 1959 additional samples were taken to a depth of 36 inches in 6-inch increments. The purpose of the latter was to ascertain the available nutrients below the 0-6 inch layer since it has been shown that potassium and magnesium move down (5) in Red Bay fine sandy loam.

Exchangeable potassium, calcium, and magnesium, available phosphorus, Walkley-Black organic matter and pH were determined on all samples. The bases were extracted with ammonium acetate buffered at 4.8. Potassium and calcium were determined on the Beckman DU flame photometer using the hydrogen flame. Magnesium was determined using sodium polyacrylate (1) and phosphorus was determined colorimetrically. Phosphorus was determined by extracting soil with ammonium acetate buffered at 4.8 and .03N NH_4F in .1N HCl (10 part extractant to 1 part soil). The latter extractant is more sensitive for determining available phosphorus on this soil since it selectively removes aluminum phosphate (6, 7).

RESULTS AND DISCUSSION

Chemical data from 1959 soil samples taken to a depth of 36 inches at 6-inch intervals from all treatments having the high level of phosphorus are shown in Table 1. The values are separated to show the effect of lime on pH, potash, calcium and magnesium. Phosphorus values for limed and unlimed plots were averaged since no significant difference for lime on phosphorus was noted. K_1 and K_3 represent 0 and 120 lbs per acre of K_2O applied annually for 8 years prior to 1958.

The lime application, which amounted to 3 tons of dolomite per acre—one ton applied 10 years before sampling and two tons applied 7 years before sampling—increased the pH and calcium values in the surface 12 inches but had little effect below this depth. The higher pH and calcium values in the 6-12 inch layer of limed soil as compared to the unlimed could have been the result of mixing in the plowing operation. Dolomitic lime increased the magnesium level to the 36-inch depth. The magnesium values for the limed soils were approximately 3 times those from the unlimed soils. Phosphorus remained in the surface which confirmed previous data (5). Residual potash in the potash-treated soil was higher to the 36-inch depth than the untreated and potash was higher where soils had been limed than where they had not.

Yield data showing response to residual potash on wheat and soybeans for the four years of the experiment are shown in Table 2. The exchange-

TABLE 1.—CHEMICAL ANALYSES OF PROFILE SAMPLE:* FROM RED BAY FINE SANDY LOAM 1959.

	pH		P_2O_5	K_2O K_1		K_5		Ca		Mg	
Depth	L	UL	L&UL	L	UL	L	UL	L	UL	L	UL
0-6″	5.6	5.2	29	48	47	162	156	892	286	108	38
6-12″	5.5	5.1	8	21	22	83	52	193	72	41	12
12-18″	5.2	5.1	6	15	19	60	55	83	81	32	13
18-24″	5.1	5.1	6	15	18	62	54	142	186	45	17
24-30″	5.2	5.2	7	16	15	73	68	199	236	61	20
30-36″	5.2	5.2	6	15	19	66	55	171	235	65	30
	5.3	5.2		22	23	84	73	280	183	59	22

*Where limed and unlimed data shown separately (Ca, Mg, and pH) figures are averages of 25 values, where they are not (P_2O_5) they are averages of 50 values. For K_2O figures are averages of 5 values. Figures represent lbs/A except pH.

TABLE 2.—WHEAT AND SOYBEAN YIELD RESPONSE TO POTASH ON RED BAY FINE SANDY LOAM (BUS/A.)*

Residual Treatment**	1958	1959	1960	1961
		Wheat		
K_1	21.5	6.6	10.6	16.8
K_2	26.4	9.5	12.8	19.9
K_3	25.4	9.8	13.3	19.8
K_4	26.7	12.5	14.9	21.7
K_5	26.4	11.8	14.9	21.3
		Soybeans		
K_1	19.5	14.2	18.3	11.6
K_2	22.5	19.4	20.7	14.9
K_3	24.0	22.1	20.9	16.0
K_4	25.2	26.2	25.0	19.3
K_5	25.6	27.3	25.5	20.7
		Exchangeable K_2O (lbs/A) (acid acetate)		
K_1	59	48	34	36
K_2	83	78	36	36
K_3	102	69	36	30
K_4	140	114	52	44
K_5	185	160	80	68

*Yield data are averages of 50 plots.
**K_1, K_2, K_3, K_4, and K_5 refer to 8 annual applications of 0, 15, 30, 60 and 120 lbs. per acre of K_2O respectively.

able potassium in the soil corresponding to the yield data are presented in the lower third of the table. Table 5 contains a breakdown of the main variables showing their significance.

An examination of the statistical data in Table 5 shows that the residual potash (treated vs. untreated) gave significant increases every year. The response is explained by the significance of linear, quadratic and cubic. When the data are put in the form of a graph the statistical data indicate the importance of the shape of the curve. There was some seasonal variation with potash response but, in general, it was more constant for soybeans than wheat. For wheat in 1958 and 1961 there was no response above the first residual (K_2). It is possible that in 1958 the first residual (70 lbs. per acre of K_2O) was adequate and by 1961 the potash in the treated plots had been depleted to such a narrow range that a yield response was not possible for wheat. However, it must be stressed here that lack of response to residual potash does not necessarily mean that supplementary potash would not give a yield response. Residual soil potash may be in a different chemical form than newly applied fertilizer potash. There was a linear response for soybeans every year which indicated that the potash residuals were not adequate for maximum yields. Inspection of the yield data indicated a greater response in the last year. Comparing the yield response

TABLE 3.—WHEAT AND SOYBEAN YIELD RESPONSE TO PHOSPHORUS ON RED BAY FINE SANDY LOAM (BUS/A.)*

Residual Treatment**	1958		1959		1960		1961	
			Wheat					
P_1	9.2		5.4		7.6		12.2	
P_2	23.0		7.7		12.0		17.6	
P_3	29.3		10.7		14.1		20.5	
P_4	32.8		12.4		16.4		24.2	
P_5	32.0		13.8		16.6		24.9	
			Soybeans					
P_1	12.2		8.9		8.1		8.9	
P_2	21.8		17.2		17.1		13.4	
P_3	24.9		24.4		24.1		16.8	
P_4	27.9		28.7		30.0		20.3	
P_5	29.9		30.0		30.0		22.9	
	Extractable phosphorus (1—.03N NH_4F, 2—4.8 NH_4 Acetate)							
	1	2	1	2	1	2	1	2
P_1	70	1	------	----	58	0	34	2
P_2	119	3	------	----	122	0	80	2
P_3	173	5	------	----	129	2	69	2
P_4	472	12	------	----	277	5	161	3
P_5	717	24	------	----	687	12	540	10
Av.	310	9			255	3	187	4

*Yield data are averages of 50 plots.

**P_1, P_2, P_3, P_4 and P_5 refer to 8 annual applications of 0, 30, 60, 120 and 240 pounds per acre of P_2O_5 respectively.

with soils data indicates that approximately 100 lbs. per acre of exchangeable K_2O was adequate for soybeans.

It was observed in the field that shedding of soybeans from dried pods was progressively greater with decreasing levels of exchangeable potash.

Table 3 contains yield data to show the response to phosphorus. Phosphorus data obtained using two extractants are shown beneath the yield data. The statistical data for phosphorus are shown in Table 5. The residual phosphorus (treated vs untreated) gave highly significant yield differences every year for both crops. For wheat the response was linear and quadratic in 1958 and linear in the remaining years. Comparing these with yield and soils data it is evident that wheat needs approximately 300 lbs. of fluoride soluble phosphorus. Fluoride soluble phosphorus decreases with time. Two factors could play a part, first, plant consumption and second, aluminum phosphorus changes to an iron phosphate and the latter is not soluble in .03N NH_4F (2). The iron phosphate is much less soluble than aluminum phosphate and hence less available to plants. Soybean yield responses seemed to discontinue at lower levels of residual phosphorus than wheat. The response was quadratic in 1959 and 1960. The yield and available phosphorus data using the two extractants already described may be compared. Again it should be emphasized that the responses indicated are for residual phosphorus. Currently applied phosphorus may not give the same responses. The acid ammonium acetate extractant does not appear to be as sensitive for determining available phosphorus as the NH_4F because of lack of specificity and narrow range.

Table 4 contains data to show the wheat and soybean response to lime. There were significant yield differences for lime every year for both crops. The chemical data showed that pH decreased with time but the difference was about the same between limed and unlimed treatments. Calcium should have decreased due to plant consumption but sampling error was apparently too large to show it. Magnesium did decrease with time probably because in addition to plant consumption, leaching took place.

CONCLUSIONS

The effects of 5 rates of residual potassium and phosphorus, and two rates of lime in Red Bay fine sandy loam on wheat and soybeans over a 4-year period were studied.

TABLE 4.—YIELD RESPONSE TO LIME IN BUSHELS PER ACRE

	Wheat*		Soybeans*		pH		Exchangeable** Ca		Exchangeable** Mg	
	L	UL	L	UL	L	UL	L	UL	L	UL
1958	26.5	24.0	25.3	21.4	5.6	5.0	520	101	160	51
1959	10.6	9.4	22.5	21.2	5.6	5.1	600	160	—	
1960	14.2	12.4	22.8	21.4	5.2	4.6	590	70	105	22
1961	20.7	19.0	18.0	14.9	5.3	4.8	716	143	49	22

*Yield differences for lime highly significant for wheat and soybeans every year. Figures are averages of 125 plots.

**Extracted with ammonium acetate buffered at pH 4.8.

TABLE 5.—STATISTICAL ANALYSES DATA OF WHEAT AND SOYBEANS*

	1958	1959	1960	1961
		Wheat		
Potash:				
Linear		00	00	
Quadratic		00		
Treated vs Untreated	00	00	00	00
Phosphorus:				
Linear	00	00	00	00
Quadratic	00			
Treated vs Untreated	00	00	00	00
Lime	00	00	00	00
		Soybeans		
Potash:				
Linear	00	00	00	00
Cubic			00	
Treated vs Untreated	00	00	00	00
Phosphorus:				
Linear	00	00	00	00
Quadratic		00	00	
Treated vs Untreated	00	00	00	00
Lime	00	00	00	00

*Two zeros (00) indicate significance at the 1% level of probability or better. Blanks indicate lack of significance. Interactions are omitted. (The authors are indebted to Dr. A. E. Brandt for the data in this table).

At the beginning of the experiment exchangeable potassium determined with acid ammonium acetate ranged from 45 to 135 lbs. per acre. After 4 years cropping the range was 36 to 68. The yields leveled off below the high values for wheat except for the last year. By the fourth year potash had dropped so low that there was not enough range in the residual treatments to give a significant yield response. Yield increases were linear to the highest level every year for soybeans. Evidently soybeans can use more residual potash than wheat. Levels of sufficiency were 70 and 100 lbs. per acre of exchangeable K_2O for wheat and soybeans respectively.

Wheat needed more residual phosphorus than soybeans. Wheat yield responses to (.03N NH_4F in .1N HCl extractable) P_2O_5 were above 300 lbs. per acre while less than 300 lbs. per acre was adequate for soybeans. The NH_4F extractant seemed more sensitive for determining available phosphorus than ammonium acetate buffered at 4.8 for reasons discussed.

It must be emphasized that yields reported were obtained for residual potassium and phosphorus. Since forms of these elements change with time, yield correlations made on residuals could be quite different from those made using currently applied fertilizer.

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Corn Yield Response to Residual Phosphorus and Potassium on Two West Florida Soil Types

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INTRODUCTION

A great deal of information has been obtained on the fertility requirements of soils within the past two decades and this has enabled agricultural scientists to make sizable advances in the production of many crops. During these years, as information has been obtained, more stress has been placed upon "prescription type" farming where soil test data are used to make fertilizer recommendations. The soil scientists have recognized for a long time that soils vary considerably within and between soil types and that the ability of the soil to accumulate plant nutrients varies according to the physical and chemical makeup within the soil. As the fertilizer usage and the knowledge of the physical and chemical properties of soils increase, the need arises to be able to correlate crop yield with the quantity of plant nutrients in the soil. This is important from the standpoint of saving the grower money and enabling him to grow a maximum economic yield. In addition, if soil technology is to gain a higher stature in the realms of soil science, the scientist must be able to intelligently, and with confidence, advise the grower on fertilizer usage. This will enable him to gain a better economic position within our society.

A series of experiments, in which five residual levels of phosphorus and potassium had been established, was used to study the yield response of corn to these two nutrients. The response to small increments of fertilizer materials, added to all residual levels, was also studied.

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METHODS

These experiments, begun in 1955, were carried out on an area designated as Series II at the West Florida Experiment Station and are an adaptation of the 5 x 5 x 5 x 2 factorial experiment which was conducted from 1950-54 (3). The original experiment was divided into five blocks which are designated by Arabic numerals. In each of these five blocks, at the beginning of these experiments, there were five replications of five fertility levels for both potassium and phosphorus as follows:

Residual Level	Lbs. P_2O_5 Per Acre Applied Annually 1950-54	Lbs. K_2O Per Acre Applied Annually 1950-54
1	0	0
2	30	15
3	60	30
4	120	60
5	240	120

Limed plots received one ton of dolomitic limestone per acre in 1950 and an additional two tons per acre in January, 1952.

Blocks 1, 2 and 5 have been used to study the effect of residual P_2O_5. Block 5 has received no additional P_2O_5 while blocks 2 and 1 have received annual applications of 30 and 60 pounds of P_2O_5 per acre, respectively, as a uniform application to all plots during the 1955-60 period. These blocks also have received annual applications of 120 pounds per acre each of N and K_2O.

Blocks 3 and 4 have been used to study the effect of residual potassium. Block 4 has received no additional K_2O while block 3 has received an annual application of 30 pounds of K_2O per acre on all plots. These blocks also have received annual applications of 120 pounds of N and 240 pounds of P_2O_5 per acre.

These blocks have been planted to Dixie 18 corn about March 20 of each year. A plant population of approximately 10,300 stalks per acre and uniform cultivation commensurate with good corn production methods was maintained on each block throughout the entire period.

The soils on which these experiments are located vary from Red Bay loamy fine sand to Norfolk loamy fine sand. Blocks 1, 2, 3 and a part of block 4 belong to the Red Bay series. The remainder of block 4 is gradational from Red Bay to the Norfolk series and block 5 belongs to the Norfolk series.

Potassium was extracted with ammonium acetate and determined to the Beckman DU[1] flame photometer using the hydrogen flame. Phosphorus was extracted from the soil with .03N NH_4F in .1N HCl and determined colorimetrically using the spectronic 20 photoelectric colorimeter.

The Red Bay loamy fine sand has better internal drainage and consequently is more droughty than the Norfolk loamy fine sand which caused yield differences in 1955 and 1960 when moisture was a limiting factor in corn production.

RESULTS AND DISCUSSION

Data for the period 1955-60 are presented in Tables 1 through 5. Each treatment value represents an average of five replications. The data show

TABLE 1.—EFFECT OF RESIDUAL P_2O_5 ON CORN YIELD
SERIES II—BLOCK 5
Bushels per acre*

Residual Treat. Level	1955 L	1955 UL	1956 L	1956 UL	1957 L	1957 UL	1958 L	1958 UL	1959 L	1959 UL	1960 L	1960 UL	Average L	Average UL
1	30	26	25	21	20	15	19	14	11	13	12	14	19.5	17.2
2	40	34	47	37	44	30	40	34	32	28	23	26	37.7	31.5
3	50	40	63	48	62	47	60	52	55	45	41	40	55.2	45.3
4	56	49	71	50	76	62	74	65	75	61	61	56	68.8	57.2
5	73	63	72	65	81	73	76	74	82	65	82	71	77.7	68.5

*15% Moisture

Legend:

Residual Levels

1 - 0 pounds of P_2O_5 applied annually - 1950-54
2 - 30 pounds of P_2O_5 applied annually - 1950-54
3 - 60 pounds of P_2O_5 applied annually - 1950-54
4 - 120 pounds of P_2O_5 applied annually - 1950-54
5 - 240 pounds of P_2O_5 applied annually - 1950-54

Fertilization

120-0-120 applied to all plots annually

L - Received one ton of dolomite per acre in fall of 1949 and two tons of dolomite per acre in January 1952.

UL - Plots have received no limestone.

TABLE 2.—EFFECT OF RESIDUAL P_2O_5 ON CORN YIELD
SERIES II - BLOCK 2
Bushels per acre*

Residual Treat. Level	1955 L	1955 UL	1956 L	1956 UL	1957 L	1957 UL	1958 L	1958 UL	1959 L	1959 UL	1960 L	1960 UL	Average L	Average UL
1	34	25	55	39	52	39	62	51	64	54	50	48	52.8	42.7
2	41	31	62	56	62	50	68	60	69	63	52	50	59.0	51.7
3	41	38	73	57	62	59	76	74	76	70	51	54	63.2	58.7
4	43	39	81	68	68	64	80	79	84	69	59	57	69.2	62.7
5	47	42	83	73	73	66	84	84	83	82	61	57	71.8	69.0

*15% Moisture

Legend:

Residual Levels

1 - 0 pounds of P_2O_5 applied annually - 1950-54
2 - 30 pounds of P_2O_5 applied annually - 1950-54
3 - 60 pounds of P_2O_5 applied annually - 1950-54
4 - 120 pounds of P_2O_5 applied annually - 1950-54
5 - 240 pounds of P_2O_5 applied annually - 1950-54

Fertilization

120-30-120 applied to all plots annually

L - Received one ton of dolomite per acre in fall of 1949 and two tons of dolomite per acre in January 1952.

UL - Plots have received no limestone.

TABLE 3.—EFFECT OF RESIDUAL P_2O_5 ON CORN YIELD

SERIES II - BLOCK 1

Bushels per acre*

Residual Treat. Level	1955		1956		1957		1958		1959		1960		Average	
	L	UL	L	UL	L	UL	L	UL	L	UL	L	UL	L	UL
1	----	----	51	46	58	42	70	60	72	57	54	52	61.0	51.4
2	----	----	61	49	61	48	75	67	70	59	52	52	63.8	55.0
3	----	----	62	55	68	58	78	77	65	65	57	55	66.0	62.0
4	----	----	78	60	69	57	81	72	84	64	56	51	73.6	60.8
5	----	----	77	66	75	69	83	81	85	73	61	58	76.2	69.4

*15% Moisture

Legend:

Residual Levels

1 - 0 pounds of P_2O_5 applied annually - 1950-54

2 - 30 pounds of P_2O_5 applied annually - 1950-54

3 - 60 pounds of P_2O_5 applied annually - 1950-54

4 - 120 pounds of P_2O_5 applied annually - 1950-54

5 - 240 pounds of P_2O_5 applied annually - 1950-54

Fertilization

120-60-120 applied annually to all plots

L - Received one ton of dolomite per acre in fall of 1949 and two tons of dolomite per acre in January 1952.

UL - Plots have received no limestone.

TABLE 4.—EFFECT OF RESIDUAL K_2O ON CORN YIELD

SERIES II - BLOCK 4

Bushels per acre*

Residual Treat. Level	1955		1956		1957		1958		1959		1960		Average	
	L	UL	L	UL	L	UL	L	UL	L	UL	L	UL	L	UL
1	42	38	76	63	65	59	73	72	70	66	51	53	62.8	58.5
2	49	43	77	67	67	60	73	68	68	70	53	53	64.5	60.2
3	48	42	78	73	71	63	78	77	78	74	63	59	69.3	64.7
4	50	45	76	72	73	64	78	77	82	68	59	55	69.7	63.5
5	51	50	74	71	73	59	79	77	83	77	58	62	69.7	66.0

*15% Moisture

Legend:

Residual Levels

1 - 0 pounds of K_2O applied annually - 1950-54

2 - 15 pounds of K_2O applied annually - 1950-54

3 - 30 pounds of K_2O applied annually - 1950-54

4 - 60 pounds of K_2O applied annually - 1950-54

5 - 120 pounds of K_2O applied annually - 1950-54

Fertilization

120-240-0 applied to all plots annually

L - Received one ton of dolomite per acre in fall of 1949 and two tons of dolomite per acre in January 1952.

UL - Plots have received no limestone.

TABLE 5.—EFFECT OF RESIDUAL K_2O ON CORN YIELD
SERIES II - BLOCK 3
Bushels per acre*

Residual Treat. Level	1955		1956		1957		1958		1959		1960		Average	
	L	UL	L	UL	L	UL	L	UL	L	UL	L	UL	L	UL
1	40	33	68	66	68	62	87	80	80	74	59	57	67.0	62.0
2	48	43	78	68	75	67	81	85	81	72	65	62	71.3	66.2
3	47	41	72	70	74	64	83	82	84	71	62	61	70.3	64.8
4	49	42	82	70	75	65	83	81	89	79	62	63	73.3	66.7
5	45	41	72	75	68	62	85	85	80	73	61	61	68.5	66.2

*15% Moisture

Legend:

Residual Levels

1 - 0 pounds of K_2O applied annually - 1950-54
2 - 15 pounds of K_2O applied annually - 1950-54
3 - 30 pounds of K_2O applied annually - 1950-54
4 - 60 pounds of K_2O applied annually - 1950-54
5 - 120 pounds of K_2O applied annually - 1950-54

Fertilization

120-240-30 applied to all plots annually

L - Received one ton of dolomite per acre in fall of 1949 and two tons of dolomite per acre in January 1952.

UL - Plots have received no limestone.

a much greater response for residual phosphorus than for residual potassium. Furthermore, the uniform annual applications of either phosphorus or potassium increased yields at the lower residual levels but had little effect at the highest residual level. Here again, the effect of applied phosphorus is larger. These data confirm fertilizer response curves obtained previously (3).

Table 6 shows "F" values obtained from the analysis of variance of each experiment. There was a highly significant interaction between residual levels and years, and residual levels and lime in some blocks. This variation was probably due to weather conditions. Differences between blocks were correlated with soil type.

TABLE 6.—ANALYSES OF VARIANCE
SERIES II - 1955-60

	Block 1	Block 2	Block 3	Block 4	Block 5
Residual Levels	55.6 **	123.9 **	9.22**	15.9 **	636.2 **
Years	80.77**	222.98**	377.25**	178.1 **	12.1 **
Years x Residual Level	3.32*	3.15**	1.77	1.05	6.94**
Lime	115.6 **	90.1 **	66.97**	42.37**	101.8 **
Lime x Residual Level	3.51*	2.31	1.42	.36	4.42*
Lime x Years	5.37**	4.55**	6.47**	3.95*	3.18*

* - Significant at 5% level of probability
** - Significant at 1% level of probability

Figure 1 shows the interaction between years and phosphate residual levels for block 5. These data show a decrease in yield response with years for all except level 5. Level 1 has received no phosphorus since the work was started in 1950 with the exception of a 30 pound P_2O_5 per acre rate as P^{32} on one yield row in 1954. The response to phosphorus is so great that the higher than usual yield of 28 bushels per acre in 1955 reflects the P^{32} addition. These data show that the residual phosphorus in the soil from prior applications kept corn yields as high as they were as the beginning of the experiment in 1955 for 0, 1, 3, 4 and 5 years for the 1, 2, 3, 4 and 5 phosphorus levels, respectively. The decrease in 1960 may be partially due to lack of moisture and, if so, additional years may indicate that the lower yield, particularly at level 4, was not due entirely to a decrease in response to the residual P_2O_5.

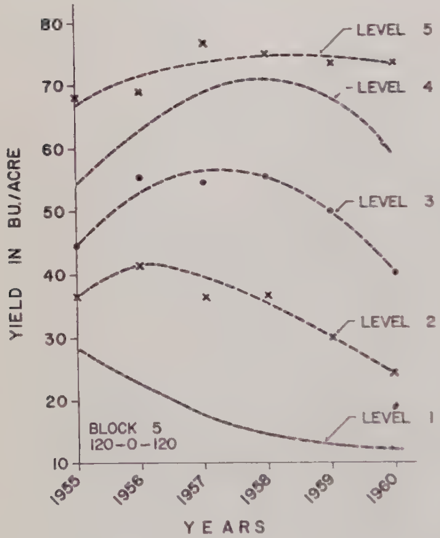

Fig. 1.—The Interaction of Years X P_2O_5 Residual Levels.

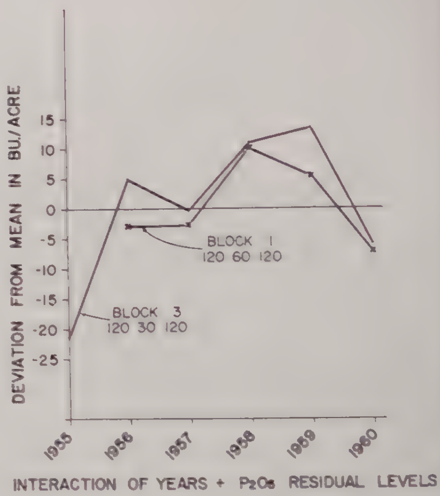

Fig. 2.—The Interaction of Years X P_2O_5 Residual Levels.

Figure 2 shows the interaction of years x phosphorus residual level for blocks 1 and 2. These data are plotted as the average deviation from the mean yield of each residual level. When these data are plotted for each level individually, it is found that the pattern is similar to Figure 2 with the deviations from mean becoming larger as the residual levels increased. These data in Figure 2 clearly show the effect of moisture on corn yield when grown on the Red Bay soil, with 1955 and 1960 being years when the greatest moisture stresses occurred. This indicates that the grower may expect a greater or lesser yield response for phosphorus depending upon available moisture during the time when the ears are forming.

Figure 3 shows the interaction between lime and residual phosphorus levels for blocks 1 and 5. On block 5, which has received no phosphorus since 1954, the response to limestone is small at the lowest P_2O_5 residual level. The response increased progressively through the 30, 60 and 120 pound P_2O_5 residual levels and decreases slightly at the 240 pound residual

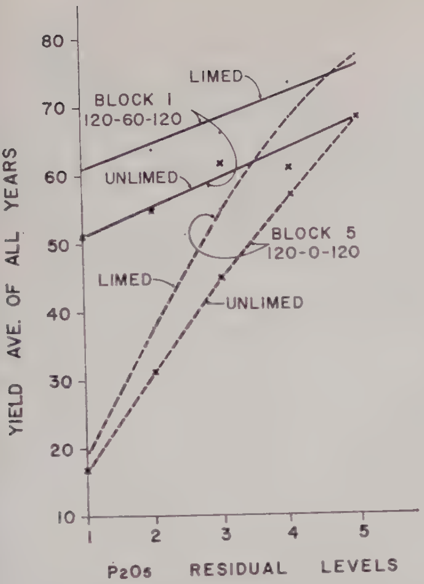

Fig. 3.—The Interaction of Lime X P_2O_5 Residual Levels.

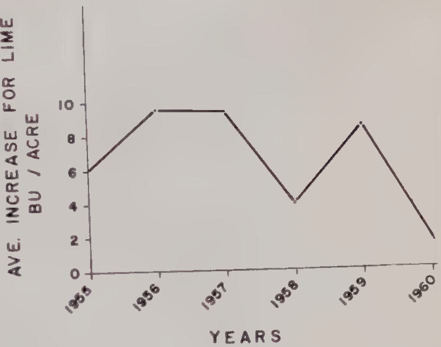

Fig. 4.—The Interaction of Lime X Years.

level. At the lower levels, phosphorus remains the major limiting factor. When 240 pounds of P_2O_5 were applied annually from 1950-54 as superphosphate, calcium equivalent to that in 1.5 tons of high calcium limestone was added. This amount of calcium has not changed the soil acidity but probably was sufficient to supply the calcium need for the corn plant. This would explain why a slight decrease in lime response might occur at the higher phosphate levels. The yield curve for block 1 is not as smooth as the one shown for block 5. This poor fit at the third and fourth residual levels is the likely cause for the significant interaction. However, there is a tendency for the increase to be smaller at the 5 than at the 1 level which could be due to the additional calcium added in the phosphate.

Figure 4 shows the interaction of Lime x Years as an average of all five blocks. When each block is plotted separately, the curve patterns are essentially the same as shown here. From these data, it is apparent that the response to limestone is more erratic than is normally supposed. A smaller response would be expected in 1955 and 1960 when moisture conditions limited yields, than in years when moisture supply was good. This was true except for 1958 when yields, on the average, were equal to or better than any other year. Yields in 1958 in blocks 3 and 4 at the lowest K_2O residual levels were relatively high and lime response in these blocks was narrow. It is postulated that this lack of response was due to near optimum moisture conditions and cloudy weather so that another limiting factor, sunlight, took precedence over limestone.

Tables 7 and 8 show the effect of time and fertilizer increments on K_2O and P_2O_5 levels in the soil, respectively. Table 7 shows that there was a sizable differential in extractable soil K_2O between the extremes in residual levels. In block 4, which received no currently applied potassium, there

TABLE 7.—EFFECT OF TIME AND POTASSIUM INCREMENT ON FIVE RESIDUAL K_2O LEVELS
Pounds K_2O per acre

	K_1		K_2		K_3		K_4		K_5	
	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed
1955 Average All Treatments	113	108	136	135	168	151	209	189	259	226
Block 4 - 1960—120-240-0	114	101	128	116	152	142	156	151	159	183
Block 3 - 1960—120-240-30	141	151	171	167	176	161	217	190	221	200

TABLE 8.—EFFECT OF TIME AND PHOSPHORUS INCREMENTS ON FIVE RESIDUAL P_2O_5 LEVELS
Pounds P_2O_5 per acre*

	P_1		P_2		P_3		P_4		P_5	
	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed
1955 Average All Levels	58*	58	77	99	138	142	240	260	539	532
Block 5 - 1960—120-0-120	99	119	94	88	101	120	151	165	296	305
Block 2 - 1960—120-30-120	115	93	102	136	111	138	168	196	389	365
Block 1 - 1960—120-60-120	115	144	127	143	159	168	195	243	364	320

*Determined by the Bray method (0.03N NH_4F in .1N HCl)

was a decrease in soil K_2O at the higher residual levels but no decrease at the first residual level. The soils used in these experiments have a medium exchangeable K_2O content under virgin conditions and these data indicate its capacity to maintain this equilibrium from the potassium-bearing minerals in the soil. In block 3 by 1960, the annual increment of 30 pounds of K_2O per acre had increased the extractable K_2O at the first and second residual levels, but the K_2O content in the soil had decreased at the highest residual level. The decrease likely has been caused by the movement of the K_2O by leaching to lower soil horizons as well as by the greater amount removed in slightly higher yields.

Table 8 shows an extremely good P_2O_5 differential among the residual levels at the beginning of these experiments. The amount of P_2O_5 was very low at the lower residual levels, but it increased progressively to a very high P_2O_5 residual at the P_5 level. The difference in the amount of P_2O_5 as determined by the Bray method (1) between limed and unlimed plots was very small throughout these experiments.

By 1960, the amount of P_2O_5 had not increased greatly at the two lower residual levels. There was an apparent increase in block 5 at the P_1 level and this may be partially explained by the P^{32} applied in 1954. There was a very definite decrease in the amount of extractable P_2O_5 at the higher P_2O_5 residual for all blocks in 1960 that cannot be explained by losses through leaching or uptake by the corn plant (5). Neller and Lundy (4) have shown that this soil fixes large amounts of phosphorus. Fiskell *et al.* (2) has found that phosphate particles in the soil become coated with colloidal aluminum and iron hydroxides and this may effectively reduce the amount extracted from the soils. Whether this condition reduces the phosphate available to plants during a growing season has not been fully determined.

SUMMARY AND CONCLUSIONS

Yield response curves for potassium and phosphorus along with the interactions for Years x Residual potassium and phosphorus, Years x Lime and Lime x Residual potassium and phosphorus have been reported for Red Bay loamy fine sand—Norfolk loamy fine sand in West Florida.

There was only a small yield response to residual potassium because the amount of available potassium in the soil was already high at the lowest residual level. Further cropping will increase the K_2O differential. However, the soils data show that it is possible to measure differences in extractable K_2O content of the soil based upon fertility history. These differences are orderly and in the expected directions. They lend credence to diagnosis by chemical means.

The data from the residual phosphorus studies showed in a very positive manner that fertilizer phosphorus is available to corn for at least six years after application. The "fixation" of phosphorus in the soil due to the formation of slowly soluble iron and aluminum phosphate is not too serious since part of the latter is available to plants. It appears that the first increments of added phosphorus are held more tightly against chemical detection than subsequent additions because, although yield response is high at the low P_2O_5 residual levels, the differences in soil phosphorus between the P_1 and P_2 levels and between the P_2 and P_3 levels are not as great as they ought to be. From these data (Table 8), there is the indication that it will be difficult to distinguish differences in the amount of residual soil

phosphorus at levels 1, 2 and 3. On the other hand, the 1955 data, which is an average of 50 observations, show an excellent stepwise increase at each phosphorus level. Additional samples will be required to reconcile these data.

The nearly 50% decrease between 1955 and 1960 in the amount of extractable phosphorus with ammonium fluoride at the highest residual level on block 5 is due to conversion of aluminum phosphate to iron phosphate. The latter being insoluble in the fluoride extractant.

This has not reduced yields to any observable extent which may mean that iron phosphate is as available to plants as aluminum phosphate. This may lead to a change in the chemical method of determining available soil phosphorus.

These data on both corn yields and extractable soil nutrients offer an excellent opportunity to correlate crop yields with years, nutrient responses, and chemical soil testing.

This paper has shown the areas and magnitudes of response to two residual nutrient elements. It is hoped that it may have established a basis for further study of sound fertilizer recommendations for the Western Florida soils.

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LIMITING FACTORS IN CORN PRODUCTION UNDER FLORIDA CONDITIONS

The Effect of Various Cultural and Fertilizer Practices on the Yield of Corn

R. L. Smith and C. E. Hutton[1]

Corn production in West Florida occupies more cultivated acreage than any other one field crop. Very low yields often occurred in the past. In the thirties and early forties most corn was produced by mule power. It was often planted in wide rows with wide spacing in the drill. Other practices included interplanting corn in alternate rows with peanuts, velvet beans or peas. Very little fertilizer was used. Corn receiving 300 pounds of 4-8-4, 3-8-5 or 2-10-4 plus 100 pounds of nitrate of soda was considered to be highly fertilized. These low rates of fertilizer along with low plant population could not produce high yields. The Mobile Units found that raising fertilizer rates with the usual low plant populations was not economical (1).

In 1944, experiments using higher rates of fertilizer in connection with increased plant populations resulted in the first major increase in corn yield for general farming in the area. Introduction of the first hybrid varieties at this time also helped in the gain in yield. It was found that yields from 20 to 30 bushels could be increased to 60 to 90 bushels with new varieties and considerably larger amounts of mixed fertilizer and nitrogenous materials for sidedressing (2). Investigations by Hutton *et al.* (3) confirmed and added to this increase in yield and now 75 to 100 bushels may be expected with normal weather conditions. At the present time, fertilizer recommendations, on a farmer basis, for corn are 400 to 600 pounds of 4-12-12 or 4-16-8 with 60 to 80 pounds of nitrogen from ammonium nitrate or other suitable nitrogenous material.

Yields as high as 300 bushels per acre have been reported in the Southeast. It was thought that with higher plant populations and still higher rates of fertilization yields could be increased in Florida. This paper presents methods and results obtained from investigations attempting to grow these very high yields of corn.

Corn Spacing: Cokers 67 corn was planted by hand with equidistant spacings of 12, 13½, 15, 18, 21, 24, 24 (3) inches and a check using 36 inch rows with corn planted 15 inches in the drill. Three to five grains were planted and the resulting stand was thinned to one stalk per hill with the exception of one 24 inch spacing where 3 stalks were left to each hill. Fertilizer at the rate of 1750 pounds of 4-12-12 were disked in prior to planting. Two 115 pound applications of N were applied as sidedressing at 30 and 40 days after planting. Irrigation was required seven times in 1960 with approximately 2 inches of water per application and only one

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TABLE 1.—EFFECT OF SPACING ON YIELD OF CORN.

Spacing in Inches	Plants Per Acre	Bushels Per Acre 1960	1961	Ave.
12	43,560	60	78	69
13½	34,400	83	94	89
15	27,875	107	106	107
18	19,360	117	112	115
21	14,220	108	104	106
24	10,890	101	100	101
24 (3)*	32,670	90	107	99
Check**	11,600	101	93	97

*Three plants per hill
**Four 38 inch rows, 15 inch spacing in drill
Soil Type: Faceville fine sandy loam
Variety: Cokers 67—March 28, 1960 and April 12, 1961
Fertilizer: 1750 pounds 4-12-12 disked in before planting
230 pounds nitrogen in split application
Cultivation: None—3 pounds Simazine in 1960 and 3 pounds Atrazine in 1961 applied as preemergence spray
Irrigation: Two inches per application—7 applications in 1960 and 1 in 1961

time in 1961. Simazine was applied at the rate of 3 pounds per acre in 1960 and Atrazine at the same rate in 1961. No cultivation was planned or attempted. The yield data are presented in Table 1.

Plant populations for 12, 13½, 15, 18, 21, 24, 24 (3) inches and check were as follows: 43,560, 34,418, 27,878, 19,360, 14,224, 10,890, 32,670 and 11,616, respectively. Yields for 1960 reached a peak with 117 bushels for the 18 inch spacing. Stink bugs which migrated from adjacent area caused some damage. Again in 1961 the highest yield came from 18 inch spacing with 112 bushels per acre. Three plants per hill in the 24 inch spacing produced 107 bushels, which was 17 bushels more than for 1960. Yields for 12 and 13½ inch spacings were also greater than in 1960. Spacings of 15, 21 and 24 inches made yields which were approximately equal to yields of these spacings in 1960. The yield of the check was 8 bushels less. Very little lodging occurred even with the highest plant population.

Highest green weight for both years was produced by 3 stalks to the hill at the 24 inch spacing (Table 2). Lowest green weights were produced by the 24 inch spacing and check which were the treatments with the lowest plant populations. There seemed to be no relation between green weights and yields of grain. Both green and dry weights for 18 inch spacing were less than that of the more highly populated treatments. In general, dry weights were directly proportional to corresponding green weights (Table 2).

Manures: The soil on which the 300 bushel yields have been made for a number of years in Prentiss County, Mississippi received a rather liberal application of manure from nearby broiler houses (4). This was in addition to large quantities of commercial fertilizer. Since no particular advantage was derived from very high quantities of fertilizer at the West Florida Station in 1960, it was thought that a portion of these very high yields could have been produced by the chicken manure. An experiment involving the use of chicken manure and rotten ensilage was carried out in 1961. Twenty and 40 tons of each material were broadcast on prepared soil and

TABLE 2.—EFFECT OF SPACING ON GREEN AND DRY WEIGHT YIELDS OF CORN

Spacing in Inches	Plants Per Acre	Green Weight Tons Per Acre 1960	1961	Ave.	Dry Weight Tons Per Acre 1960	1961	Ave.
12	43,560	32.8	27.7	30.3	9.1	6.9	8.0
13½	34,400	32.9	27.4	30.2	8.7	6.5	7.6
15	27,875	31.4	32.0	31.7	8.8	8.2	8.5
18	19,360	29.7	29.2	29.5	7.5	7.4	7.5
21	14,220	29.6	31.1	30.4	8.3	7.8	8.1
24	10,890	23.5	25.5	24.5	6.5	6.9	6.7
24 (3)*	32,670	35,5	30.6	33.1	9.4	8.0	8.7
Check**	11,600	24.5	23.6	24.1	6.4	6.7	6.6

*Three plants per hill
**Four 38 inch rows, 15 inch spacing in drill

incorporated with a Killifer harrow. Twenty-five hundred pounds per acre of 4-12-12 were applied in this operation. Cokers 67 corn was planted in 19 inch rows with a 17 inch spacing in the drill. One-hundred pounds of N were applied 30 days and again at 40 days after planting. A pre-emergence application of 3 pounds of Atrazine was broadcast for weed control. No cultivation was attempted. Due to excessive rainfall immediately after planting, the stand was poor. Two inches of water was applied once and moisture from summer rains was plentiful thereafter.

The results are shown in Table 3. During the growing season, corn with both rates of poultry fertilizer grew faster than, and began to tassel before, corn on other treatments. However, the advantage in growth began to level off as maturity was reached. All yields were lower than expected and were almost equal with the exception that the treatment receiving 40 tons of chicken manure produced 8 bushels more. Yields of this magnitude should be produced with recommended practices on average years.

High Bed Versus Conventional Beds: Cokers 67 corn was planted in bedded or hilled rows in comparison with the conventional or furrow method. All plots received a uniform application of 1200 pounds of 10-10-10 before planting and 155 pounds of N from calcium ammonium nitrate

TABLE 3.—EFFECT OF ORGANIC MATTER ON YIELD OF CORN

Treatment	I	II	III	IV	Ave.
Check	105	66	96	86	88
20 T. Chicken Manure	82	80	97	76	84
40 T. Chicken Manure	99	90	119	92	98
20 T. Ensilage	93	75	98	83	87
40 T. Ensilage	74	79	109	93	89

Date of Planting: April 12, 1961
Variety: Cokers 67—Stand: Fair
Fertilizer: 2500 pounds 4-12-12 disked in prior to planting
100 pounds N 30 days after planting and again at 40 days
5 pounds borax mixed with calcium ammonium nitrate
Cultivation: None—3 pounds Atrazine applied as preemergence spray
Irrigation: 2 inches of water at one application

TABLE 4.—EFFECT OF METHOD OF PLANTING ON YIELD OF CORN

	Yield in Bushels per Acre					
	L-1		L-2		L-3	
Treat.	Hill.	Con.	Hill.	Con.	Hill.	Con.
1	104	111	106	114	114	121
2	99	101	99	124	101	117
3	94	100	87	101	87	110
4	96	100	97	100	97	112
5	70	95	93	98	97	116
6	55	70	93	100	89	103
Ave.	86	96	95	106	98	113

Fertilizer: March 16—1200 pounds 10-10-10 disked in
May 24—155 pounds N from calcium ammonium nitrate
L-1—2 tons dolomitic limestone 1954—pH 6.0
L-2—2 tons dolomitic limestone plus 1½ tons high calcium limestone—pH 6.0
L-3—2 tons dolomitic limestone plus 3 tons high calcium limestone—pH 6.1

as a sidedressing. As shown in Table 4, three rates of lime were used. This area also had received heavy applications of fertilizer in preceding years.

There was a small increase in yield due to lime. Yields from the conventional method were about 10 bushels higher than those of the hilled plots. Lodging was more prevalent on the hilled plots than where the conventional method was used.

Incorporation of Sawdust in Soil at Various Levels With an Extremely High Rate of Fertilizer and High Rates of Lime: Five-hundred pounds of N, 750 pounds of P_2O_5, 500 pounds of K_2O and 3 tons of dolomitic lime-

TABLE 5.—EFFECT OF INCORPORATED SAWDUST WITH HIGH FERTILITY ON YIELD OF CORN

	Yield in Bushels per Acre					
Treat.	I	II	III	IV	V	Ave.
1	99	75	98	93	84	90
2	87	84	92	74	81	84
3	100	85	90	98	105	96
4	95	96	109	71	97	94
5	106	85	72	90	72	85

Variety: Florida 200, spacing 8 to 10 inches in 19 in. rows
Fertilizer: Jan. 18—500 pounds N - 750 pounds P_2O_5 - 500 pounds K_2O
Mar. 21—3750 pounds 4-12-12 disked in
May 15—400 pounds N as sidedressing from ammonium nitrate
Treat. 1—Plowed 7½ inches deep
Treat. 2—Plowed 15 inches deep
Treat. 3—Plowed 7½ inches deep—50 tons sawdust incorporated
Treat. 4—Plowed 15 inches deep—50 tons sawdust incorporated 7½ in. to 15 in. level
Treat. 5—Plowed 15 inches deep—50 tons sawdust incorporated 0 in. to 15 in. level
Soil Type: Faceville fine sandy loam
Lime: 1955—1¼ tons dolomitic limestone
1956—2 tons dolomitic limestone
1961—4½ tons dolomitic limestone

stone were disked into the soil in January, 1961. Fifty tons of sawdust were incorporated in each 7½ inch level on all treatments receiving sawdust. These treatments were: (1) Incorporated in the 0-7½ inch level; (2) Incorporated in the 7½-15 inch level and (3) Incorporated in the 0-15 inch level. Treatments plowed to a depth of 7½ and 15 inches were used as check. Fertilizer at the rate of 3750 pounds of 4-12-12 and 1.5 tons of dolomitic limestone was disked in prior to planting. Florida 200 corn was planted in 19 inch rows with a spacing of 8 inches in the drill on April 22. Three pounds of Atrazine was applied as a preemergence treatment for weed control. Nitrogen from calcium ammonium nitrate was applied at the rate of 400 pounds of N per acre.

The data, as presented in Table 5, shows no appreciable advantage for incorporation of sawdust in this manner. It is possible that these plots may produce more corn when the sawdust has decayed. Yields, in spite of the very heavy applications of fertilizer were no higher than expected from recommended practices for corn. Water was applied by overhead irrigation when rainfall was insufficient to provide ample moisture.

Carbon Dioxide and Reflected Light: A preliminary experiment involving the addition of carbon dioxide to corn in plastic enclosures and the reflection of light by aluminum foil was carried out in 1961. Results show no advantage for either method when compared to the check plots.

SUMMARY AND CONCLUSION

It may be assumed from these and other data equally as conclusive that high plant populations, high fertility and irrigation are not the answer to the problem of getting yields consistently above 100 bushels per acre.

Applications of 20 and 40 tons of chicken manure or rotten ensilage to highly fertilized corn gave no appreciable increase in yield.

Incorporation of 50 tons of sawdust per acre at two levels failed to increase yields of highly fertilized corn. A total of 1050 pounds of N, 1200 pounds of P_2O_5, 950 pounds of K_2O and 4.5 tons of limestone were applied to this corn.

Over 100 bushels of corn per acre were grown without cultivation when preemergence herbicides were used.

Corn planted by the conventional method made yields which were approximately 10 bushels higher than corn which was planted on hilled or raised beds. This corn was also highly fertilized and yields were approximately 100 bushels.

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The Effects of Spacing, Hybrids and Varieties, Fumigation and Mulches on Yields of Highly Fertilized Corn[1]

W. H. CHAPMAN[2]

Corn is the most important field crop in Florida. Prior to 1950 the average yield per acre was low; however, much progress in the improvement of corn yields has been made in recent years. Yield per acre in Florida has increased approximately 2½ times since 1945. This increase in acre yields has been closely associated with the substitution of improved hybrids for open-pollinated varieties as well as the use of more fertilizer, increased plant populations, and improved tillage and soil management practices.

Recently farmers have become more interested in intensive culture of field corn. Although county corn-growing contests have demonstrated that yields in excess of 100 bushels per acre are possible, methods followed to obtain these high yields were arrived at arbitrarily. At present no specific recommendations for economical production of such high yields are available in Florida. If further significant yield increases are to be obtained, additional information must be secured on the various factors which are limiting corn yields.

This paper reports the results of exploratory studies involving plant populations, hybrids, mulches and soil fumigation on yields of highly fertilized corn.

LITERATURE REVIEW

Wofford *et al.* (7) reviewed work in Florida on spacing and nitrogen fertilization of field corn prior to 1956. In general, populations in excess of approximately 6,000 stalks per acre and applications of more than 60 pounds of nitrogen per acre as sidedressing did not produce significant increases in grain yields (1, 2, 4, 6).

Since 1956, research indicates that levels higher than those mentioned above can be used. Wofford *et al.* (7) with a population of 7,000 plants per acre obtained no increase in yield when nitrogen applications were increased from 100 to 200 pounds per acre; however, with 11,000 plants and increasing the nitrogen from 100 to 220 pounds raised the yield from 69 to 84 bushels per acre. In these experiments, the number of ears per plant and the average weight per ear decreased with higher rates of planting. Prine *et al.* (5) reported increased production of grain and forage up to 17,000 plants per acre, the highest population used. However, nitrogen rates over 100 pounds per acre plus approximately 60 pounds from a cover crop did not increase grain or silage yields. Horner *et al.* (3) did not obtain significantly higher yields, even with high populations, when nitrogen applications heavier than about 200 pounds per acre were applied. When plant spacing was varied at nitrogen rates up to 460 pounds per

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acre, grain yields leveled off at approximately 17,000 stalks per acre. Except for corn-growing contests, populations higher than 13,000 plants per acre were not recommended. At these populations nitrogen applications in excess of 100 to 130 pounds per acre were not profitable.

MATERIALS AND METHODS

Soil analyses of the area used in 1960 and 1961 are given in Table 1. Samples were taken in the spring prior to fertilizer applications and during the 1961 growing season. Early in 1960, 1.5 tons per acre of dolomite lime were applied to the area. One ton of 4-12-12 containing zinc sulfate was harrowed in to a depth of 6 inches prior to planting, and the corn was sidedressed with 700 pounds ammonium nitrate per acre in three applications. Coker 67 hybrid corn was planted equidistantly with plant populations ranging from 10,980 to 43,560 plants per acre and in 36-inch rows at 10,890 plants per acre. One series of plots with low, medium and high populations (10,890, 19,360 and 43,560 plants per acre respectively) was fumigated with methyl bromide prior to planting. Plots with low and medium populations were mulched with pine straw, black plastic or a white opaque material when the corn was approximately 5 feet high. Irrigation was used as needed. A broadcast treatment of Simazin applied before emergence adequately controlled weeds and no cultivation was used.

TABLE 1.—SOIL ANALYSES OF AREA PLANTED TO HIGH FERTILITY STUDIES IN 1960 AND 1961

	Feb. 1960	Dec. 1960	Apr. 1961	June 1961
pH	5.60	6.31	5.96	5.70
P_2O_5 (lbs./A)	16	27	31	21
K_2O (lbs./A)	183	141	274	368
Ca (lbs./A)	378	841	820	742
Mg (lbs./A)	199	246	350	332

In early 1961, one ton per acre of dolomite lime was applied and immediately prior to planting one ton of 4-12-12 was plowed under. A sidedressing of 508 pounds of N, 250 pounds of K and 158 pounds of Ca from a mixture of ammonium nitrate, muriate potash, nitrate potash and calcium nitrate was applied in three applications. Coker 67, a prolific hybrid; Hastings, a prolific open-pollinated variety and Sims, a single-eared open-pollinated variety were planted with plant populations ranging from 9,680 to 29,040 plants per acre. One series of plots containing medium and high populations were treated with a 5 percent granular experimental nematocide. One treatment was planted on a bed in comparison to the usual listing method of planting.

RESULTS

Spacing: In 1960, yields of Coker 67 hybrid were not significantly different at populations of 10,890, 14,244, 19,360 or 27,878 plants per acre; however, each of these populations produced significantly higher yields

TABLE 2.—EFFECT OF SPACING ON YIELD, PROLIFICY, AND NUMBER OF STALKS STANDING OF COKER 67 HYBRID CORN IN 1960.

Spacing	No. Stalks Per Acre	Bu. Per Acre	No. Ears Per Stalk	Percent Stalks Standing
12 x 12	43,560	63	.71	10
15 x 15	27,878	95	1.04	9
18 x 18	19,360	95	1.28	15
21 x 21	14,224	93	1.58	30
24 x 24	10,890	101	1.83	55
16 x 36	10,890	94	1.81	46
L.S.D. .05		13	.04	15
.01		17	.05	15
C.V.		10%	6%	26%

than that of 43,560 plants per acre (Table 2). Also, the difference between equidistant spacing and 3-foot rows containing a comparable number of plants per acre (10,890) was not statistically significant. Lodging increased and the number of ears per stalk decreased as populations increased. With the high fertility of this experiment (315 pounds N - 240 pounds P_2O_5 - 240 pounds K_2O) lodging was excessive in all plant populations.

Since very high plant populations from equidistant spacings showed little promise in 1960, only the 18 x 18 inch spacing (19,361 plants per acre) was included in 1961. Other treatments were added including variations within 3-foot rows. Also, fertilizer applications were increased to a total of 588 pounds N, 240 pounds P_2O_5 and 490 pounds K_2O. With this fertility program plant populations of 14,520, 19,360 and 29,040 plants per acre in various kinds of spacings produced significantly higher yields than that of 9,680 plants per acre (Table 3). Similar yields were obtained from plant populations of 14,520 plants per acre whether spaced 12 inches in 3-foot rows or 6 inches in alternating narrow and wide rows (1½ feet and 6 feet between rows). There was no significant difference from 19,360 plants per acre arranged either 9 inches in 3-foot rows or 18 inches in 3-foot rows with 2 plants per hill. An equidistant spacing of 18 inches x 18 inches produced 138 bushels per acre which is significantly higher than any other spacing included in the experiment. Plant populations of 29,040 plants per acre produced similar yields when spaced either 6 inches in 3-foot rows or 18 inches in 3-foot rows with 3 plants per hill. Lodging in all treatments and varieties was very severe.

In 1960, the number of ears per stalk decreased rather rapidly as the plant populations increased. Since no data on the performance of open-pollinated varieties under high fertility conditions are available, Hastings Prolific and Sims single-ear, two open-pollinated varieties, were included to see if prolificy could be maintained with thick populations. Results of this test are given in Table 4. Increases in the yield of Coker 67 at populations of 14,520 or 29,040 plants per acre as compared to 9,680 plants per acre were highly significant. In contrast, there was no significant difference in the yield of Hastings prolific at the three spacings and a significant decrease in the yield of Sims from the medium (14,520 plants per acre) to the high (29,040 plants per acre) population. Also, a greater decrease in prolificy of the open-pollinated varieties as compared to the hybrid was noted.

TABLE 3.—EFFECT OF SPACING ON YIELDS OF COKER 67 HYBRID CORN IN 1961.

Spacing	No. Stalks Per Acre	Bu. Per Acre
18 x 18	19,360	138
6 x 36	29,040	117
9 x 36	19,360	122
12 x 36	14,520	106
18 x 36 1 plant per hill	9,680	85
18 x 36 2 plants per hill	19,360	111
18 x 36 3 plants per hill	29,040	104
6 x 36 Narrow and Wide Row Spacing	14,520	102
L.S.D. .05		16
.01		22
C.V.		12%

These data indicate the striking superiority of improved hybrids over open-pollinated varieties under high fertility conditions.

Fumigation: In 1960, yields on plots fumigated with methyl bromide were significantly higher at plant populations of 43,560 and 19,360 plants per acre and approached significance with 10,890 plants per acre (Table 5). Percent of root lodging (stalk leaning from ground level because of root system pulling out of soil) on fumigated plots was significantly lower than on unfumigated plots and the number of lesion nematodes, (*Pratylenchus brachyurus*), in soil or roots was greatly reduced. Stuby root, (*Trichororus christiei*), ring (*Circonemondes curuatum*) and spiral (*Helicotylenchus nannus*), nematodes were few to moderately numerous in both fumigated and non-fumigated plots.[3] Root systems from fumigated plots were much larger (Figure 1) and the corn appeared more uniform and even in height than in treated plots.

In 1961, differences in yield between the untreated plots and those treated with a granular experimental nematocide were not significant (Table 6). Nematology examinations showed few to moderately numerous

TABLE 4.—EFFECTS OF SPACING ON YIELD AND PROLIFICY OF COKERS 67 HYBRID AND HASTINGS PROLIFIC AND SIMS SINGLE-EARED VARIETIES OF CORN IN 1961.

Spacing	No. Plants Per Acre	Yield in Bu. Per Acre			No. Ears Per Stalk		
		Cokers	H.P.	Sims	Cokers	H.P.	Sims
18 x 36	9,680	85	73		1.40	1.39	
12 x 36	14,520	106	81	82	1.16	1.14	.74
6 x 36	29,040	117	71	61	.86	.67	.48
L.S.D. .05		16	16	16	.17	.17	.17
.01		22	22	22	.23	.23	.23
C.V.		12%	12%	12%	12%	12%	12%

[3]Acknowledgment is made to Department of Entomology for nematode counts and identification.

TABLE 5.—EFFECT OF SOIL FUMIGATION WITH METHYL BROMIDE ON YIELD, PROLIFICY, PERCENT STALKS STANDING AND AVERAGE NUMBER OF ROOT LESION NEMATODES IN SOIL AND ROOTS OF COKER 67 HYBRID CORN IN 1960.

Spacing	Number Stalks per acre		Bushels per acre	Number ears per stalk	Percent root lodging	Average Lesion in Soil	Number Nematodes in Roots
12 x 12	43,560	Fumigated	82	.79	7		
		Not fumigated	63	.71	46		
18 x 18	19,360	Fumigated	108	1.26	3		
		Not fumigated	95	1.28	21		
16 x 36	10,890	Fumigated	104	1.86	2	3	2
		Not fumigated	94	1.81	10	460	468
L.S.D. .05			13	.04			
.01			17	.05			
C.V.			10%	6%			

nematodes in all plots sampled. Apparently nematodes were not as numerous as the previous year.

Mulches: Differences in yield of plots mulched with pine straw, black plastic or the white opaque material were not significant (Table 7). Soil temperatures were uniform under the pine straw but by 2 p.m. had increased about 4° C. under the black plastic and 2° C. under the opaque material. These increases were maintained until sometime after 6 p.m. but temperatures at 8 a.m. were equal under the three mulches. Root systems appeared to be more vigorous and extensive where the mulches were applied. The observation that the average of root lesion nematodes was less in the soil and roots of plots receiving mulches was of interest. This was especially true of the number in the soil.

Bedding vs. Listing: Listing or planting in furrows is the common practice in most southern soils. It was thought that planting on elevated ridges or beds might cause better aeration of the roots and a better root development. However, no visible difference in the root systems from the two methods of planting and no significant differences in yields were noted.

TABLE 6.—EFFECT OF NEMATOCIDE TREATMENT ON YIELDS OF COKER 67 HYBRID CORN IN 1961.

Spacing	No. Stalks Per Acre		Bu. Per Acre
6 x 36	29,040	No treatment	117
	29,040	Nematocide	121
12 x 36	14,520	No treatment	106
	14,520	Nematocide	113
L.S.D. .05			16
.01			22
C.V.			12%

Fig. 1.—Corn roots from plots fumigated with methyl bromide (left) and unfumigated plots (right).

Corn planted in the furrow produced 122 bushels per acre in comparison to 115 bushels planted on a bed.

DISCUSSION

Present recommendations for field corn production make possible yields of 60 to 80 bushels per acre. By increasing the plant population and applying heavier rates of fertilizer, yields of approximately 100 bushels per acre can be obtained with adequate moisture. However, yields in excess of this amount are rather uncommon and the methods for obtaining such

TABLE 7.—EFFECT OF MULCHES ON YIELD, PROLIFICY, AND AVERAGE NUMBER OF ROOT LESION NEMATODES IN SOIL AND ROOTS OF COKER 67 HYBRID CORN IN 1960.

Spacing			Bushels per acre	No. Ears per Stalk	Average Lesion in soil	No. Root Nematodes in roots
18 x 18	19,360	No mulch	95	1.28		
18 x 18	19,360	Pine straw	100	1.38		
16 x 36	10,890	No mulch	94	1.81	460	468
16 x 36	10,890	Pine straw	82	1.74	79	384
16 x 36	10,890	Black Plastic	100	1.83	160	314
16 x 36	10,890	White opaque	102	1.82	139	270
L.S.D. .05			13	.04		
.01			17	.05		
C.V.			10%	6%		

yields are somewhat sporadic. The exploratory studies reported in this paper were conducted to obtain additional information on the various factors which are limiting corn yields.

Under the conditions of these experiments populations higher than 20,000 plants per acre did not produce increased yields. At high populations there was increased lodging, decreased ear size and a pronounced reduction in number of ears per stalk. Considering all these factors, results of these studies would not warrant changing recommendations of Horner *et al.* (3) that except for corn growing contests, populations higher than 13,000 plants per acre are not recommended. High fertility levels were definitely not economical.

One of the most interesting observations from these studies was that the yields were obtained with a relatively poor root system. Excavation of plants from a depth of 20 inches showed no significant difference in size of root system except from the fumigated areas in 1960. No visible differences were observed in 1961 between roots from an area where the fertilizer was mixed in the top 15 inches and where it was harrowed into the soil. Possibly significant increases in yield could be obtained by putting more emphasis on the development and growth of the root system. This would particularly apply to its distribution and resistance or tolerance to insects and diseases.

Factors such as limited amounts of light and carbon dioxide or unfavorable seasonal temperatures could be responsible for the apparent ceiling on corn yields. Also, it is possible that hybrids such as Dixie 18, Florida 200 and Cokers 67 are adversely affected by close spacings and high fertility under growing conditions in Florida and we have more or less reached the yielding capacity of the hybrids now being grown. Zuber (8) reported the results of a questionnaire mailed to experiment station workers to obtain the highest recorded yield and the factors limiting corn yields in various states. Factors suggested that may limit corn yields in Florida in order of their probable relative importance were as follows: (1) low soil fertility, (2) inadequate plant populations, (3) inadequate rainfall, (4) poor cultural practices and (5) insects. It appears that studies in Florida during the past two years have tended to disprove importance of at least the first three of the above factors and added yielding capacity of the hybrid, lodging, and root development and distribution.

SUMMARY

Exploratory studies were conducted in 1960 and 1961 to study the effects of plant populations, hybrids and open-pollinated varieties, soil fumigation, mulches, and bedding on highly fertilized field corn.

Populations higher than 20,000 plants per acre did not produce increased yields. With high populations, there were increased lodging, decreased ear size and a pronounced reduction in number of ears per stalk.

Yields of Coker 67 hybrid were significantly increased by thick populations; however, the plant populations used in this test did not affect the yields of the open-pollinated varieties. Also, there was a greater decrease in prolificy of the open-pollinated varieties at close spacings as compared to the hybrids.

Yields on plots fumigated with methyl bromide were significantly higher

than from unfumigated plots. Percent root lodging was lower and the corn appeared more uniform and even in height in the untreated plots.

There was no significant difference in yields from plots mulched with pine straw, black plastic or a white opaque material.

There was no visible difference in the root systems and no significant difference in yield between corn planted in a furrow and on a bed.

Under the conditions of these tests, yielding capacity of the hybrid, lodging, and root development and distribution appeared to limit yields. High fertility levels were not economical.

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Response of Field Corn Varieties to Plant Populations and Planting Dates on Flatwoods Soil[1]

A. J. NORDEN[2]

Flatwoods soils constitute a large part of the total land area of Florida. In recent years, with values of farm lands increasing in Florida, along with the need to feed an expanding livestock industry, increased attention is being given to the use of flatwoods soils for more intensive types of crop production. Because of the high water table, flatwoods soils have not been used extensively for the production of cultivated field crops. Flatwoods soils are level to nearly level and, in their natural state, have a fluctuating supply of water, the control of which is often a limiting factor in field crop production.

Since corn has not generally been grown on flatwoods soils in Florida, corn production research on these soils is very limited. Field corn production has been studied rather intensively in Florida on upland soils. However, correlation between research obtained from upland soils and that obtained from flatwoods soils would be expected to be low and subsequently comparisons between them would not be desirable. This study

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was conducted to determine the effect of five plant populations and two planting dates on grain yield, plant height, ear height, ear weight, number of ears per plant and percent lodging of two hybrid corn varieties grown on flatwoods soil.

LITERATURE REVIEW

Preliminary trials, with five leading hybrid corn varieties in 1958 and with 16 hybrid corn varieties in 1959, indicated that satisfactory grain yields could be obtained on flatwoods soils, but that the optimum plant population, variety and planting date may be different than those for corn grown on upland soils (7, 8). In a report of the yield potential of these soils, Robertson (9) obtained corn yields as high as 150 bushels per acre on flatwoods soil in 1959.

Literature relating to corn plant spacing and planting date tests on upland soils in Florida, prior to 1956, was reviewed by Wofford *et al.* (10). Results prior to 1956 indicated that in general on upland soils, where moisture is a limiting factor, corn should be planted at 6000 to 7000 plants per acre.

Wofford *et al.* (10), from a study of plant populations and planting dates conducted at the Main Station at Gainesville in 1955, obtained no significant increase in yield as the stand was increased above 7000 plants. Highest yields were obtained from plantings made between March 15 and April 15 and no significant interactions were obtained between planting date and plant populations. In a 1956 test, Wofford *et al.* (10) included nitrogen levels along with plant populations and planting dates and obtained highest yields at combinations of 11,000 plants with 200 pounds of nitrogen and 13,000 plants with 160 pounds of nitrogen. They found that altering the plant population had a greater effect on yield than varying the nitrogen level, and that the yield of corn declined as date of planting was delayed after March 1.

Horner *et al.* (4) studied the effect of planting date, plant population, nitrogen levels and irrigation on field corn production at the Main Station at Gainesville in 1956 and 1957. Early March plantings produced higher yields than late March or mid-April plantings in both years. They found that at high nitrogen rates, when moisture was not limiting, grain yields leveled off at approximately 17,000 plants per acre. However, because of stalk breakage, approximately 13,000 plants per acre was recommended for commercial production even under irrigation. On soils that are low in fertility and moisture-holding capacity, lower populations may be more desirable.

EXPERIMENTAL PROCEDURE

The experiments were conducted on Leon fine sand located at the Beef Research Unit, Gainesville, Florida. Three row plots, 16.5 feet long with 38 inches between the rows were used in 1960 and 19.25 feet long with 38 inches between the rows in 1961. The varieties, Florida 200 and Coker 811, were planted March 25 and April 14, 1960, and March 10, 1961. The plant populations were 5,000, 10,000, 15,000, 20,000, and 25,000 plants per acre. Twelve replications were used.

The experimental area had been in a grass-white clover mixture for several years prior to 1960. A surface drainage ditch, approximately two feet deep, was located at one end of the area. On the basis of soil analysis, a surface application of a mixture of 500 pounds of 4-8-16 fertilizer, 200 pounds of gypsum, 40 pounds of No. 501 Fritted Trace Elements and 5 pounds of Aldrin was made per acre each year and disked in prior to planting. The corn seed was treated with a fungicide and crow repellent and hand planted with two kernels per hill, later thinned to one plant per hill. The hills were spaced 33.00, 16.50, 11.00, 8.25 and 6.60 inches apart in the row to obtain populations of 5,000, 10,000, 15,000, 20,000 and 25,000 plants per acre respectively. One and one-half pounds per acre of the herbicide Simazine was sprayed in bands over the rows immediately after planting. The plots were sidedressed with a split application of 66 pounds of nitrogen per acre and were hoed once for weed control and spot dusted as needed for bud worm control. No machine cultivation was used.

The corn ears were harvested from the center row of each plot in 1960 and from an 8¼ foot mid-section of the center row of each plot in 1961. The 8¼ foot yield sample in 1961 consisted of 3, 6, 9, 12 and 15 plants for the populations 5, 10, 15, 20 and 25 thousand plants per acre respectively. Data on plant height, ear height, ear numbers, ear weight and number of lodged plants were obtained at physiological maturity from the area of the plot sampled for grain yield determinations. Small underdeveloped ears were not included in the data. Yield measurements were adjusted on the basis of moisture determinations.

Precipitation recorded in the vicinity of the experimental plots during the months of March, April, May and June in 1960 was 7.20, 2.80, 2.38 and 8.05 inches, respectively, and the 1961 precipitation during these months was 1.38, 2.81, 2.32 and 9.02 inches, respectively.

RESULTS AND DISCUSSION

Plant population had a highly significant and similar effect on the yield of grain of two corn hybrids from March plantings on flatwoods soil in 1960 and 1961 (Table 1). As the plant population increased from 5,000 to 25,000 plants per acre in 1960, mean grain yield increased from 105.5

TABLE 1.—MEAN GRAIN YIELD FROM MARCH PLANTINGS OF TWO HYBRID CORN VARIETIES AT FIVE POPULATION LEVELS ON FLATWOODS SOIL IN 1960 AND 1961.

Population (Plants per acre)	Grain Yield - Bushels per acre, 15% moisture 1960			1961		
	Variety			Variety		
	Fla. 200	Coker 811	Mean	Fla. 200	Coker 811	Mean
5,000	110.0	101.0	105.5	53.5	54.9	54.2
10,000	113.7	115.2	114.5	69.5	70.2	69.8
15,000	119.1	118.1	118.6	80.9	69.0	74.9
20,000	127.3	132.0	129.6	81.5	84.7	83.1
25,000	136.0	128.0	132.0	79.9	71.3	75.6
Mean	121.2	118.9	120.0	73.0	70.0	71.5
L.S.D. (5% level)			7.4			11.6
L.S.D (1% level)			10.0			15.7

to 132.0 bushels per acre. In 1961 the mean yield increased from 54.2 to 83.1 bushels per acre within the 5,000 to 20,000 plants per acre range, but yield decreased 7.5 bushels as the population was increased from 20,000 to 25,000 plants per acre.

A significantly lower mean yield of grain was obtained in 1961, 71.5 bushels per acre as compared to 120.0 bushels per acre in 1960. This 40 percent reduction in yield in 1961 is believed to be due largely to a shortage of moisture during the critical silking period. As was shown previously, the 1961 season was less favorable in regard to the amount of rainfall early in the season and the water table level in the plot area had dropped to a depth of more than 3 feet below the soil surface during the period May 5 through June 20, 1961. In studies of soil moisture stress at different stages of growth on yield of corn, Denmead and Shaw (2) obtained a 50 percent reduction in yield from a lack of water for 17 days during silking time. Boyd (1) obtained higher corn yields on 12 and 24 inch water levels than where the water level was 36 inches below ground surface. Because of the complex nature of the water-soil-plant interrelationships, the optimum water table level for a crop such as corn is not known. Meyer and Anderson (6) stated that water seldom rises through the soil by capillarity from the water table at an appreciable rate for heights of more than a few feet. In studies of the depth of water table on yield of Ladino clover, orchard grass and tall fescue on a soil in the tidewater area of North Carolina, Gilbert and Chamblee (3) found that water tables below 6 inches did not supply sufficient moisture for maximum yield of grasses when no surface water was applied, and that during drought, Ladino clover would be most benefitted by maintaining a water table of approximately 6-12 inches.

The two-year summary of agronomic data and yield results from March plantings of hybrid corn on flatwoods soil is shown in Table 2. Yields at the various population levels are higher than those reported from population studies on upland soils at Gainesville (10) and as high as yields reported in studies on upland soils where irrigation was added (4). Number of ears per plant and weight per ear decreased as plant population increased. Ear height and plant height increased as the plant population was increased from 5,000 to 10,000 plants per acre, then the heights

TABLE 2.—SUMMARY OF AGRONOMIC DATA AND YIELD FROM FIVE PLANT POPULATIONS OF CORN FROM MARCH PLANTINGS ON FLATWOODS SOIL AT GAINESVILLE, FLORIDA. (DATA REPRESENTS THE MEAN OF 48 PLOTS FOR THE TWO-YEAR PERIOD, 1960-61).

Population Plants per acre	Bus. per acre 15% moisture[1]	No. ears per plant	Ear weight (lbs.)	Ear height (inches)	Plant height (inches)	Percent plants lodged	Percent ear moisture at harvest
5,000	79.9	2.5	.40	56.5	96	2	34
10,000	92.2	1.6	.38	58.6	102	2	34
15,000	96.8	1.2	.38	58.3	102	7	34
20,000	106.4	1.1	.34	59.4	102	9	34
25,000	103.8	0.9	.33	59.1	101	10	33

[1]L.S.D. (5% level) 6.9, (1% level) 9.3

leveled off and were fairly uniform until at the highest population, at which plant and ear heights were somewhat shorter. The percent of lodged plants increased with increasing population but was not considered serious in the March plantings in this study at any of the population rates. However, if the corn in these studies had been allowed to stand in the field for a period after ripening, as is frequently the case in commercial production, lodging results might have been different. A 1% decrease in percent ear moisture at harvest was obtained at the high population rate.

Planting date had highly significant effects on yield of corn on flatwoods soil and a significant Date of Planting x Plant Population interaction was obtained. These results, shown graphically in Figure 1, suggest that if planting is delayed on flatwoods soils, the plant population should be reduced. The great increase in lodging which was obtained for the April planting at the 25,000 plant population would be considered undesirable in recommending higher populations. As planting is delayed after early March the water table on flatwoods soil drops until the June rainy season arrives. Letey and Peters (5) showed that sub-soil moisture reserve at the beginning of the season is closely related to corn yield and concluded that a dry sub-soil apparently slows down the downward advance of roots through the profile. The curvilinear response to increased plant population in the April planting of this test is very similar to results reported by Horner *et al.* (4) for a March planting on upland soils under irrigation in which they obtained a leveling off of yield in the 11,000 to 19,000 plant population range.

Yields of the March, 1960 planting were increased significantly by increasing populations up to 20,000 plants per acre, while in an April planting, yields were not significantly increased beyond the 10,000 plants per acre level (Table 3). Reduced ear weight was a major factor in the lower

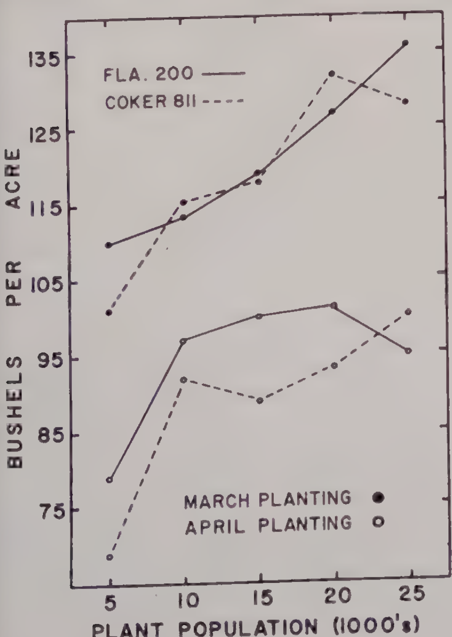

Fig. 1.—Effect of Plant Population, Variety and Planting Date on Yield of Corn on Flatwoods Soil in 1960.

yields from the April planting. The reason for the increased lodging in the April planting is not clear. Plant and ear height for the April planting averaged 1 inch shorter. Possibly lodging was caused by a combination of factors involving the physiological conditions of the roots and culms in relation to the condition of the soil. Late planted corn in Florida is exposed to a period of more ample moisture conditions usually, and therefore would not be expected to have as large a root system in relation to the above ground portion of the plant. The drier soil at the time of the later planting would likely result in slower root development, and growth later in the season would likely be hindered by the excess summer rainfall. Boyd (1) noted that lodging was more severe in corn grown at 12 inch water levels as compared to 24 and 36 inch levels. Horner *et al.* (4), from a test on upland soil with irrigation, reported that high wind in September of 1957 had severely lodged an April 15 planting but did not seriously affect two earlier plantings.

TABLE 3.—SUMMARY OF THE EFFECTS OF PLANTING DATE AND PLANT POPULATION ON YIELD AND AGRONOMIC CHARACTERISTICS OF CORN GROWN ON FLATWOODS SOIL AT GAINESVILLE, FLORIDA IN 1960. (DATA REPRESENTS THE MEAN OF 24 PLOTS)

Treatments							
Population (Plants per acre)	Planting Date	Bus. per acre, 15% moisture[1]	No. ears per plant	Ear weight (lbs.)	Ear height (inches)	Plant height (inches)	Percent plants lodged
5,000	March 25	105.5	2.8	.45	55.5	105	3
	April 14	73.8	2.5	.36	56.3	105	1
10,000	March 25	114.5	1.7	.43	57.9	110	3
	April 14	94.7	1.9	.34	55.2	108	6
15,000	March 25	118.6	1.3	.43	58.0	111	4
	April 14	94.5	1.4	.32	58.5	111	9
20,000	March 25	129.6	1.2	.39	59.8	112	2
	April 14	97.3	1.2	.30	58.0	111	6
25,000	March 25	132.0	1.0	.37	60.6	111	4
	April 14	97.2	1.0	.28	56.3	111	22

[1]L.S.D. (5% level) 7.0

Plant populations and planting date had a pronounced effect on the average ear weight for the corn hybrids in this test (Figure 2). Variation in ear weight due to varieties, plant populations and to the interaction of varieties with plant population was significant at the 1% level in both the March and April planting dates. The ear weight of Florida 200 dropped sharply beyond the 15,000 plants per acre rate, especially in the March planting, whereas ear weight of Coker 811, after a sharp drop between the 5,000 and 10,000 rates declined gradually. The reduced weight per ear of Coker 811 at the 15,000 rate was offset somewhat by the fact that it averaged .2 more ears per plant at this population than did Florida 200. Although the conditions under which the hybrids used in this study

were selected is not known, it is expected that a differential response of genotypes will be obtained to the environmental conditions imposed at high population densities on flatwoods soil.

SUMMARY

The response on flatwoods soil of two hybrid corn varieties to five plant populations and two planting dates was studied at Gainesville, Florida in 1960 and 1961. Results are reported on grain yield and agronomic characteristics, including plant height, ear height, ear weight, number of ears per plant and percent of plants lodged.

In the March, 1960 plantings, as plant population was increased from 5,000 to 25,000 plants per acre, grain yield increased from 106 to 132 bushels per acre. In 1961 the mean yield increased from 54 to 83 bushels per acre with an increase in population from 5,000 to 20,000 plants. However, yield decreased 7 bushels as the plant population was increased from 20,000 to 25,000 plants per acre. These results suggest that the optimum plant population for flatwoods soils where moisture is usually not limiting might be higher than those recommended for the well-drained upland soils.

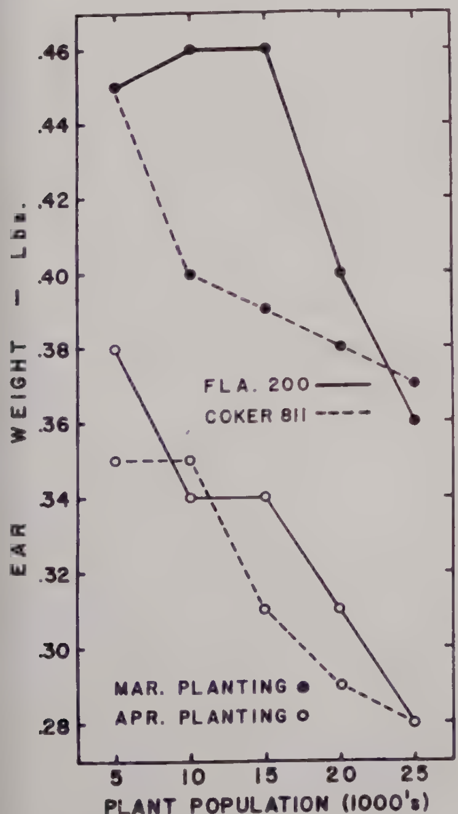

Fig. 2.—Effect of Plant Population and Date of Planting on Ear Weight of Two Varieties of Corn on Flatwoods Soil in 1960.

A significant date of planting x plant population interaction was obtained, indicating that optimum plant population for flatwoods soil will vary depending on time of planting. Yields from a March planting in 1960 were increased significantly by population increases up to 20,000 plants per acre, while yields in the April planting were not increased significantly by populations above 10,000 plants per acre. The months of March, April and May are usually lower in rainfall in Florida and the water table is in a downward trend which undoubtedly is a factor in these results and indicates that on flatwoods soils, especially in late plantings, moisture can be a factor limiting corn yields. The percent lodging was a serious problem in the April planting, especially at the 25,000 plants per acre rate.

Both ear weight and number of ears per plant were decreased by increasing plant populations, and late planting resulted in a marked decrease in ear weight without appreciably affecting the number of ears per plant.

A highly significant plant population x variety interaction was obtained in regard to weight per ear in both the March and April plantings, indicating that different genotypes react differently to the environmental conditions existing in a high plant population.

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Light, A Factor to Be Considered in Growing Corn[1]

GORDON M. PRINE[2]

Plants depend upon light as the source of energy for all their life processes. Consequently, optimum light conditions are essential for the best plant growth and development. The light environment of plants is often overlooked because it is so obvious or because often nothing can be done easily or economically to change it.

In an earlier paper Prine[3] discussed various factors necessary for maximum production of corn. Light was pointed out as a probable limiting factor under the conditions necessary for producing maximum yields. The results of several experiments were presented supporting the above contention. This paper is a report of several experiments studying further the effect of light as a limiting factor. The experiments were designed to create more favorable light conditions for corn growing in the normal field environment and to measure the resulting plant response.

EXPERIMENT 1. INTERPLANTING OF TALL AND SHORT CORN VARIETIES

Introduction: If light is a factor limiting corn production then any management practices which will appreciably increase the amount of light received by corn plants should give an increase in production. How to increase the amount of light available to corn plants under field conditions without large changes in the other environmental factors presents a serious problem. It was theorized that if an early maturing, short variety of corn such as US 13 was grown in alternate rows with a late maturing, tall variety of corn such as Fla. 200, then the irregular plant canopy would allow full sunlight to penetrate lower on the tall corn plants with less shading of bottom leaves than in a solid stand of tall plants. The short variety would reach maturity approximately two weeks before the tall variety and give an additional advantage to the tall corn late in season as a result of decreased competition for light and other environmental factors by the short corn. It was also thought that the yields of the short, early maturing hybrid might be similar whether grown in alternate rows with tall corn or in solid stand. In this case, the total yield of the interplanted short and tall rows might exceed that of either hybrid alone.

Materials and Methods: In 1960 and 1961, US 13 and Fla. 200 were planted in solid stand and interplanted in alternate single and double rows. Four replications of the treatments listed in Table 1 were planted each year on March 8. A nearly perfect population of corn plants was obtained for Experiments 1, 2, 3, and 4 by seeding two or more kernels by hand in equally spaced hills and then thinning to one plant per hill when seedlings were in 6-leaf stage. Irrigation water was applied to bring soil moisture to field capacity when a 1.25 inch deficit occurred from just before

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[3]Prine, G. M. A report of several experiments studying ecological and physiological problems related to maximum corn production in Florida. Soil and Crop Science Society of Florida Proceedings. Vol. 20: 50-61. 1960.

tassel emergence on U.S. 13 corn plants until maturity of Fla. 200. Soil moisture levels were determined by the water budget method assuming an evapotranspiration rate of .20 inches per day. The soil used in this experiment, as well as other experiments reported in this paper, was Arredondo fine sand. Uniform heavy fertilization was made in an attempt to remove fertilizer nutrients as factors limiting growth of the corn. During the growing season of 1960 fertilizer materials were applied to corn plots at the following rates per acre:

35 pounds of fertilizer grade epsom salts
2100 pounds of calcic limestone
900 pounds of dolomitic limestone
260 pounds of nitrogen
110 pounds of phosphoric acid
280 pounds of potash
6 pounds of zinc sulfate
4 pounds of copper sulfate
25 pounds of complete fritted minor element mixture (F.T.E. 501)

During the growing season of 1961 fertilizer materials were applied to corn plots at the following rates per acre:

2000 pounds of dolomitic limestone
400 pounds of nitrogen
160 pounds of phosphoric acid
400 pounds of potash
120 pounds of epsom salts
9 pounds of zinc sulfate
30 pounds of complete fritted minor element mixture (F.T.E. 501)

The corn rows were fumigated with 1 and 1⅓ gallons per acre in 1960 and 1961, respectively, of a fumigant containing 71% 1,2-dibromo-3-chloropropane. In both seasons, 4 pounds per acre of aldrin was applied broadcast with fertilizer and disked in soil several weeks before seeding. Row spacing in both 1960 and 1961 was 38 inches. Six row plots were 30 feet long in 1960 and 22.5 feet long in 1961. Yield of ear corn, number of plants and number of ears per plot were determined on the middle two rows of plots in solid stands. When varieties were interplanted, these determinations were made on the middle four rows of each plot, two rows for each hybrid. All measurements pertaining to grain or ear yield in this report are on the basis of dry matter as determined by drying in a 130° F forced air drier to constant weight. Yield of corn per acre was determined on the basis of 70 pounds of ear corn per bushel.

Results and Discussion: The grain yield of US 13 and Fla. 200 growing alone in pure stand and in alternate single and double rows with each other is given in Table 1. The yield of US 13 is available only for 1960 because severe damage from wildlife made yield data from this variety worthless in 1961. The yields of US 13 planted in alternate rows with Fla. 200 were slightly lower than yields of solid planted US 13. The greatest reduction in grain yield of US 13 occurred where Fla. 200 was planted every other row. Interplanting single rows of Fla. 200 between single rows of US 13 resulted in increased yield of the Fla. 200. The yield of US 13 was so much lower than Fla. 200, that yields of Fla. 200 and US 13 interplanted together were not as good or only as good as Fla. 200 alone. However, it appears that greater production per acre might be obtained by planting

TABLE 1.—THE GRAIN YIELD OF A SHORT, EARLY MATURING CORN VARIETY (US 13) AND A TALL, LATE MATURING CORN HYBRID (FLORIDA 200) GROWN ALONE IN SOLID STAND AND INTERPLANTED IN ALTERNATE SINGLE AND DOUBLE ROWS.

Corn planted	Thousands of plants per acre	Bushels per acre 1960 US 13	1960 Fla. 200	1960 Avg.	1961 Fla. 200	2-Year avg. Fla. 200
US 13 every row	9	89		89		
Fla. 200 every row	9		117	117	101	109
Fla. 200 every row	18				104	
Fla. 200 and US 13 in alternate single rows	9	81	125	103	111	118
Fla. 200 and US 13 in alternate single rows	18	96	150	123	136	143
Fla. 200 and US 13 in alternate double rows	9	84	116	100	106	111
Fla. 200 and US 13 in alternate double rows	18	103	140	122	111	126
L.S.D. .05		8	17	9	19	11
.01		12	24	13	NS	15

equally adapted and yielding, short early and tall late hybrids in alternate rows than from either hybrid in solid stand.

The 50 percent silking stage was reached by the US 13 about two weeks earlier than by Fla. 200 in both seasons. In 1960 the US 13 and Fla. 200 plants were 8 to 9 and 9 to 10 feet tall at maturity, respectively. Plants of both varieties were about a foot shorter in 1961. The shorter US 13 plants allowed additional light to reach the lower portions of the Fla. 200 plants where the two varieties were interplanted on alternate rows. This additional light is believed to be the main contributing factor to the increase in yield of 32 bushels per acre obtained from interplanted Fla. 200 over solid stand at the 18000 plants per acre population in 1961. There was little difference in grain yields of solid and interplanted Fla. 200 at the 9000 plants per acre population in either 1960 or 1961, though yields tended to be higher when interplanted in single rows with US 13. The excellent yields of Fla. 200 at the 9000 population in 1960 indicate that all environmental factors including light were very favorable in this season.

The weight of ear corn per plant, weight of ears and number of ears per plant for Fla. 200 as affected by treatments are shown in Table 2. The ear weight was changed very little by either population or interplanting treatment. Differences in yield of grain per plant and consequently yield per acre were largely the result of changes in the number of ears per plant. Florida 200 had the highest number of ears per plant at the 18000 plants per acre population when the Fla. 200 was interplanted in single rows with US 13. Ear number per plant was highest where treatments gave the most favorable light conditions.

EXPERIMENT 2. SPECIAL ENVIRONMENT THROUGH TOPPING

In an adjacent area to Experiment 1 in 1960, another approach was used to create a more favorable light environment for Fla. 200 corn plants. Replication, plot size, fertilization, irrigation and other management prac-

TABLE 2.—THE AVERAGE WEIGHT OF CORN PER PLANT, EAR WEIGHT AND EARS PER PLANT OF FLORIDA 200 CORN GROWN IN SOLID STAND AND INTERPLANTED IN ALTERNATE ROWS WITH US 13.

		1960			1961		
Fla. 200	Plants 1000's/A.	Ear corn yield per plant (lbs.)	Ear weight (lbs.)	Ears per plant	Ear corn yield per plant (lbs.)	Ear weight (lbs.)	Ears per plant
in every row	9	.86	.42	2.03	.61	.40	1.51
in every row	18	—	—	—	.44	.39	1.14
in alternate rows with US 13	9	.94	.44	2.11	.63	.41	1.56
in alternate rows with US 13	18	.58	.38	1.52	.54	.39	1.39
in alternate double rows with US 13	9	.84	.42	1.99	.60	.40	1.50
in alternate double rows with US 13	18	.56	.40	1.39	.45	.40	1.14
L.S.D. .05		.10	.04	.12	.10	NS	.27
.01		.14	NS	.17	.13	NS	.38

tices were the same as for Experiment 1. In this study corn plants with the normal environment of a solid stand of corn were compared with corn plants having a more favorable light invironment created by cutting the tops off Fla. 200 corn plants in adjacent rows. The tops were removed above the 10th leaf when silks were showing on about 10% of the plants. The upper ear shoot usually developed in the axil of the 9th leaf. Grain yields, plant number and ear number were determined on 2, 20-foot sections of row for each plot.

The average weight of ear corn per plant and per acre, ear weights, and ears per plant are presented in Table 3. Yield of grain per plant was highest where plants on adjacent rows were topped. Part of the light usually intercepted by the top portion of the topped plants struck the lower portion of untopped plants giving these plants a more favorable light environment. Under the conditions of the special environment, the increased grain yield per plant was due to the increased number of ears per plant.

EXPERIMENT 3. INTERCROPPING OF CORN WITH PEANUTS AND SOYBEANS

Florida 200 corn was planted at 9000 and 18000 plants per acre in solid stand and at a rate of 18000 plants per acre in double rows separated by double rows of soybeans and peanuts in 1960. The bushels per acre yield and experimental procedure of this experiment have been reported.[4] The effect of growing corn in pure stands and intercropping are reported in Table 4. In this experiment also, the difference in yield per plant is due mostly to the increased number of ears per plant and not to the difference in weight of individual ears. The average grain per plant at 18000 plants per acre was 61% of the average grain per plant at 9000 plants. The grain per plant and number of ears per plant were higher where corn with a row population of 18000 plants per acre was intercropped with peanuts and soybeans than when grown in solid stands. The ear weight per plant and ears per plant were greatest under the best light conditions, that is, low population and intercropped with peanuts and soybeans.

[4] *Ibid.*

TABLE 3.—A COMPARISON BETWEEN GRAIN YIELD PER PLANT, EAR WEIGHT AND EARS PER PLANT OF FLORIDA 200 CORN AT A POPULATION OF 15000 PLANTS PER ACRE UNDER TWO ENVIRONMENTAL CONDITIONS IN 1960.

Treatment	Average over four replications		
	Ear corn per plant (lbs.)	Ear weight (lbs.)	Ears per plant
A. Normal environment	.56	.42	1.35
B. Special environment[1]	.62	.40	1.58
Difference significant at level	.05	NS	.05

[1]The special environment was created by cutting the tops from corn plants on both sides of corn row harvested above the 10th leaf from ground when silks were showing on 10 percent of plants.

EXPERIMENT 4. LIGHT REFLECTION STUDY

Introduction: Even at high populations of corn some sunlight penetrates to the soil level without being intercepted. Light reaching the soil is absorbed by the soil or reflected where it can be used by plants in photosynthesis. If a highly reflective material, such as aluminum foil, is placed on the soil surface it will reflect much of the light usually absorbed by the soil, enhancing the amount of light available to the lower portions of corn plant. This portion of this paper gives the preliminary results of a field experiment studying the effects of aluminum foil reflectors on the growth of corn at Gainesville in 1961.

Procedure: Coker 67 corn as seeded on plots 6 rows wide by 25 feet long. Distance between rows was 38 inches. Treatments consisted of plant populations of 15000 and 30000 plants per acre with no aluminum foil reflectors, aluminum foil reflectors in every middle, and aluminum foil reflectors in every other middle. Where the aluminum foil was applied every other middle, the tips of leaves were removed so as to have an open corridor 2 feet wide for sunlight to penetrate to the foil. An additional treatment was included to measure the effect of cutting the tips of the

TABLE 4.—THE EFFECT UPON THE GRAIN YIELD PER PLANT, EAR WEIGHT, AND EARS PER PLANT FROM INTERPLANTING TWO ROWS OF FLORIDA 200 HYBRID CORN ALTERNATELY WITH TWO ROWS OF EITHER PEANUTS OR SOYBEANS.

Planting arrangement	Corn plants in row 1000's/A	Ear corn per plant (lbs.)	Ear weight (lbs.	Ears per plant
Solid corn	9	.75	.37	2.00
Solid corn	18	.46	.35	1.29
2 rows corn - 2 rows peanuts	18	.56	.37	1.54
2 rows corn - 2 rows soybeans	18	.53	.37	1.46
L.S.D. .05		.11	NS	.14
L.S.D. .01		.14	NS	.20

TABLE 5.—THE AVERAGE GRAIN YIELD PER PLANT, EAR WEIGHT AND NUMBER OF EARS PER PLANT OF COKER 67 CORN PLANTED AT TWO POPULATIONS AND RECEIVING SEVERAL LIGHT REFLECTION AND LEAF REMOVAL TREATMENTS AT GAINESVILLE IN 1961.

Plants 1000's/A	Reflection and cutting treatment	Weight of ear corn per plant (lbs.)	Ear weight (lbs.)	Number of ears per plant	Grain yield (bu./A)
15	Check	.46	.37	1.23	99
15	Aluminum foil in every middle	.56	.38	1.49	119
15	Aluminum foil in every other middle with tips of leaves removed over foil	.47	.37	1.28	101
15	Tips of leaves removed every other middle	.43	.37	1.15	90
30	Check	.25	.29	.86	99
30	Aluminum foil every middle	.30	.32	.94	111
30	Aluminum foil in every other middle with tips of leaves removed over foil	.30	.31	.97	118
30	Tips of leaves removed every other middle	.21	.28	.74	87
	L.S.D. .05	.07	.04	.12	16
	L.S.D. .01	.10	.05	.16	21

leaves from the corn. The 8 treatments listed in Table 5 were replicated 5 times. All fertilization, irrigation, and other management were the same as given for corn in Experiment 1 for 1961.

Two reflectors of 18-inch wide aluminum foil were placed on the slopes of the middles, one on each side of the flattened "V" made by the hilled corn rows. The cracks remaining between the sheets of foil in the center of the middle and at the row allowed rain and irrigation water to reach the soil and provided air exchange between soil and atmosphere. The aluminum foil and leaf cutting treatments were made May 16 through 18 when corn plants had 12 to 14 leaves expanded and were 5 to 6 feet tall with no tassel emergence from boot. The plants reached the 50 percent silking stage on May 31.

Results and Discussion: The average yield of ear corn per acre and per plant, weight of ears and number of ears per plant as influenced by the various population and light reflection treatments are shown in Table 5. Plots with aluminum foil reflectors in every middle between corn rows at a population of 15000 plants per acre yielded 20 bushels per acre more than the same population without reflectors. The aluminum foil in every other middle at the low population was no better than the normal plot. This was apparently due to the detrimental effect of removing the tips of leaves from the corn plants. As in other experiments reported in this paper, the difference in yield per acre and per plant at the same population resulted mainly from differences in number of ears per plant and not from changes in ear weight. There was a difference in ear weight between the 15000 and 30000 plants-per-acre populations, the ears of the 30000 population being lighter.

At the high corn population the increase in yield from aluminum foil

reflectors in every row was much smaller than at the low plant population. This would be expected as much less light penetrated to the foil to be reflected.

There is no wish to infer that the aluminum foil reflectors did not affect other factors of the environment besides light. Certainly the foil formed a vapor barrier which prevented evaporation from the soil surface and probably affected normal aeration also. Moreover, the foil reflected light which normally would have been absorbed as heat by the soil. Temperatures of soil and air on plots with and without foil were measured for several days in June at the 15000 population. During daytime, the temperatures of air and soil of plots covered with foil were several degrees warmed and cooler, respectively, than in plots without foil. The irrigation water schedule is believed to have satisfactorily prevented soil moisture deficits capable of significantly reducing the yields of plots not covered by foil and having normal soil moisture evaporation.

At the 30000 plant population, the treatment with aluminum foil in every other middle and with leaf tips removed gave the highest grain yields. The more favorable environment created by the aluminum foil resulted in a 31 bushels-per-acre increase in grain yield over the untreated plot with the tips of leaves removed. Much of this increase in yield would appear to be from giving light to light-starved plants and not to better soil moisture conditions due to decreased evaporation. It would be expected that the treatment with aluminum foil in every middle would have had highest grain yields if the latter condition was most effective.

GENERAL DISCUSSION

Light conditions become generally less favorable over the lower portions of corn plants as the plant populations increase. The fact that light energy available to each plant diminishes with each addition of a plant to a unit of area creates a situation in which, if population is increased enough, light becomes limiting. Data from the four experiments reported in this paper show increased yields of grain per acre and per plant whenever treatments were made that would increase the amount of light received by the corn plants. The increased yields were mainly the result of an increase in average number of ears per plant. Ear weights remained very nearly the same for a given population of plants regardless of light-improvement treatment used.

The improved yield per plant under the more favorable light conditions gives evidence that light was limiting maximum corn production. It was not possible to design a field experiment which would change the light factor without changing other factors too. However the experimental techniques used, especially in Experiments 1, 2, and 4, seem to offer more favorable light conditions with a minimum change in other environmental factors, so that effects of treatments on corn plants would be mainly that of the light factor.

The production of 200 bushels of corn per acre using adapted prolific hybrids would require at least 15000 plants per acre each having two well-developed ears. Such corn plants are most common in populations below 10000 plants per acre. Research workers have generally failed to reach the goal of 200 bushels per acre in yields. Research reported in this paper indicates that their failure may be due to inability of adapted prolific hybrids to produce two or more ears on all plants under the normal light

environment found at the high plant populations needed. When plant population is increased to the level necessary for such a high yield from only one ear per plant the environmental stress is so great that ear weights are reduced and the goal is not reached. The reported yields in excess of 200 bushels per acre may be unique situations in which conditions for corn growth are at or near optimum and abnormally high levels of CO_2 or some other factor complementary to light acts to increase the efficiency of the corn plants in utilization of light energy present.

The tendency for ear weight to stay constant over a wide range of light and other environmental conditions raises the question of whether the effect of light on number of ears per plant is crucial over a short or long period in the development of the plant. Can one or two cloudy days at a critical period in the life of the plant result in reducing the number of ears on a prolific corn plant from three to two, or two to one or one to none? Research is needed to determine the physiological mechanism controlling the number of ears on corn plants and the role that light indirectly or directly plays in this mechanism.

SUMMARY

Four field experiments are reported which give evidence that light is an important limiting factor when corn is grown at high populations. Light conditions were made more favorable at several different plant populations up to 30000 plants per acre by the methods of (1) planting tall and short corn varieties in alternate rows, (2) topping plants on alternate corn rows, (3) interplanting corn with soybeans and peanuts, and (4) placing aluminum foil reflectors on soil. Better light conditions resulted in increased grain yields per acre and per plant mainly because more ears were produced per plant. Ear weight remained the same under wide variation in light conditions, though extreme environmental stress, such as increasing population from 15000 to 30000 plants per acre, did reduce ear weight. Apparently, the first effect of inadequate light on prolific corn hybrids is reduction in number of ears per plant. Ear weight may be reduced also, if light is extremely limiting.

Carbon Dioxide, as it Affects Corn Yields[1]

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Corn yields in Florida have increased annually for several years. In 12 years the yield has gone up over 200%, yet the average yield per acre in Florida is still estimated at less than 30 bushels. Factors generally listed as limiting corn production are rainfall distribution, soil fertility, disease and insects, and yielding ability of hybrids. Other components of the natural environment of corn such as carbon dioxide (CO_2), light, and temperature have received little attention as possible factors limiting corn growth. The development of improved hybrids, use of high rates of fertilization, improved cultural practices, and high plant populations accent the importance of light and carbon dioxide in corn production.

In the process of photosynthesis plants remove CO_2 from the air. The CO_2 absorbed from this source must be replaced by wind movement, diffusion, or CO_2 evolved from the soil. Lemon (2) developed an aerodynamic method of determining the turbulent carbon-dioxide exchange between the atmosphere and a corn field. Moss, Musgrave, and Lemon (4) showed that soil respiration did not release enough carbon dioxide to supply rapid rates of photosynthesis in corn. Schroder and Ruelke (7) working with pasture grasses in Florida found that photosynthesis often utilized 2 to 3 times the amount of CO_2 given off by plant and soil respiration combined. Iowa State University scientists (1) studying the conditions resulting in a 300 bushel corn yield in Mississippi estimated that 50 tons of chicken manure applied per acre would supply at a maximum only 10 percent of the CO_2 needed to produce this crop. All this serves to point out that most of the CO_2 need for plant growth must come from the atmosphere. On the other hand it is also known that increased growth will result if the CO_2 levels are increased around a plant. For example, Musgrave and Moss (5) showed that significantly more CO_2 was assimilated by corn leaves supplied with 510 ppm CO_2 as compared with 290 ppm which corresponds to atmospheric concentration. If it were possible to increase the CO_2 levels under field conditions higher yields might result. The purpose of this paper is to establish the role of CO_2 as a possible limiting factor and to report several field experiments in which attempts were made to reduce the possibility of CO_2 being a limiting factor.

METHODS

Experiments were conducted on three different soil types: Arredondo, Klej, and Kanapaha fine sands.

On the Arredondo fine sand at Gainesville the experiment was treated uniformly with fertilizer, lime and minor elements. Details are listed in the footnote of Table 1. The soil was fumigated with 1.3 gallons per acre of fumazone 70E before planting. After planting a 14-inch band was

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sprayed with simazin immediately over the corn rows to control weeds. The corn was cultivated twice, the last cultivation coming when the corn was about knee high. All plots were irrigated at least once a week to bring the soil to field capacity. A daily loss of water by evapotranspiration of 0.21 inch was assumed. Each plot consisted of six rows 38 inches apart and 22 feet long. Coker 67 corn was planted. Relatively fresh chicken manure (hereafter referred to as manure), having no chemicals added and containing very little extraneous material, was used as a treatment. It was applied at 45 tons per acre before the ground was plowed. Carbon dioxide was supplied directly from cylinders and indirectly from oxidation of the manure. Nine enclosures[3] eight feet square and eight feet high were set up in the corn field when the corn was shoulder high (Figures 1 and 2). These enclosures were covered on the sides with fiber glass cloth which reduced wind movement and also cut down light. Carbon dioxide was released from cylinders through rubber tubing to capillaries at ground level in the center of three enclosures. Under normal conditions there would be approximately 4.5 liters of carbon dioxide in the enclosure at any one time (3) and as the corn used it, it would be replenished from the soil through respiration of organisms in the soil and by the corn itself. The gas was released from 8 A.M. to 5 P.M. daily at the rate of 10 liters per hour for the first two weeks and then increased to 1 liter per minute for approximately 5 weeks or until six 50-pound cylinders of carbon dioxide were used. By this time the corn was practically mature.

Ear leaf samples were taken at tasselling time and analysed chemically to determine concentrations of nitrogen, phosphorus, potassium, calcium, and magnesium. Corresponding analyses and pH were made on surface

TABLE 1.—1961 YIELD RESULTS FROM CORN FERTILITY EXPERIMENT ON ARREDONDO FINE SAND NEAR GAINESVILLE.

Treatment*	Yield bus./A	Stalks /Acre	Wt. /Ear	Ears /Stalk
1. Check	122	15600	.49	1.14
2. Enclosures	106	20000	.40	1.04
3. Enclosures + Chicken Manure	117	17500	.44	1.00
4. Enclosure + CO_2	121	16900	.44	1.08
5. Chicken Manure	114	16600	.45	1.02
Average	116	16900	.45	1.06
L.S.D. 5%	N.S.	N.S.	N.S.	N.S.

*Management and uniform fertility treatments as follows:
(a) Feb. 15, 945 lbs. A 0-10-20 plowed in followed by surface application of 810 lbs. A 4-8-16 disked in.
(b) Feb. 24, area fumigated with fumazone 70E at rate of 4/3 gal./A.
(c) Planted Mar. 31 followed by simizine at rate of 2 lbs./A.
(d) Mar. 28, 24-25-10-25-3 lbs. per/A of N-P_2O_5-Mg-frit 501-Zn respectively.
(e) Apr. 15, 230 lbs./A urea.
(f) May 11 and May 23, 600 and 250 lbs./A respectively of NH_4NO_3 with lime (20.5%N).

[3]The authors are indebted to R. H. Sharpe of the Fruit Crops Department, Fla. Agr. Exp. Sta. for supplying the enclosures.

Fig. 1.—A close up of 1 enclosure at the time it was installed. Enclosure covers 3 rows 8′ long.

(0-6″) soil samples. The carbon dioxide evolution from the soil in all treatments and the distribution of the gas within the enclosures were measured with an infrared gas analyzer (6). Corn yield data consisted of stand, ears per stalk, weight per ear and corn grain in bushels per acre.

Dixie 18 corn was planted in the experiment on Klej fine sand near Live Oak. Treatments consisted of four replications of 6-row plots, 40 feet long and 36″ apart. The area was irrigated regularly during dry periods as in the preceeding experiment. Nutrients were supplied with 5-10-15 fertilizer. Minor elements were a variable. A mixture of several minor elements was applied at the rate of 10 lbs. per acre to the treated plots. Carbon dioxide was supplied through the oxidation of the manure. Carbon dioxide evolution from the soil, chemical data from ear leaf and soil samples at tasselling time and corn yield data similar to the preceding experiment were used as a measure of response.

The third experiment was located on Kanapaha fine sand also near Gainesville. Treatments consisted of 4 replications of 6-row plots, 40 feet long and 38″ apart. Coker 71 corn was planted. Rates of fertility were

Fig. 2.—Showing the distribution of the enclosures in the corn experiment

tested on corn planted in 38-inch rows and corn planted alternately, two rows planted and two left unplanted. Both plantings received the same amount of fertilizer. The criteria of response were ears per stalk, stalks per acre, and corn grain per acre. Soil analytical data from samples taken at tasselling time were used to support yield data.

All corn yields were calculated on the basis of 70 lbs. per bushel of ears at 15.5% moisture.

Late blight and helminthosporia affected the corn at all locations and reduced yields.

RESULTS AND DISCUSSION

Yield results from corn grown on Arredondo fine sand are contained in Table 1. Differences were not significant at the 5% level of probability. However, enclosures reduced the yield 16 bushels below the check. The addition of 45 tons of manure increased the yield 11 bushels and CO_2 brought the yield up comparable with the check. Manure without the enclosure produced less than the check. There was no consistent differences in stalks per acre, weight per ear or ears per stalk.

The carbon dioxide data in Table 2 showed that at the high rate of CO_2 release, the levels within the enclosures were considerably above normal. The dispersal pattern was fairly good being very high at the point of release and decreasing toward the top and sides with a slight accumulation in the corners. Any air movement would tend to shift the released CO_2

TABLE 2.—TYPICAL DISTRIBUTION PATTERN OF CARBON DIOXIDE INSIDE ENCLOSURES WHEN CARBON DIOXIDE GAS WAS RELEASED AT RATE OF 1 LITER PER MINUTE EXPRESSED AS PERCENT OF NORMAL AIR CONCENTRATION.

Distance from center of enclosure in feet	Height above ground in feet								
	0	1	2	3	4	5	6	7	8
0	>270	135	140	120	117	110	107	100	100
1	155	150	135	121	115	107	100	100	100
2	121	121	128	114	107	107	110	100	100
3	100	104	114	107	107	100	100	100	100
4	100	103	107	102	105	100	100	100	100
5 (in corners)	114	104	117	114	107	107	104	100	100

to one side of the enclosure or disperse it so rapidly that increased levels could not be measured. The fiber glass cloth on the walls restricted air movement somewhat but since it was porous the CO_2 would diffuse through it and on occasion when there was a breeze increases in CO_2 could be measured at the 2 and 3 foot levels immediately outside of the wall. No consistent increases could be measured in the enclosures when CO_2 was released at the rate of 10 liters per hour and no increases or decreases were measured in checks or enclosures with the manure treatment with the exception of a 3% decrease measured in one enclosure. It should be pointed out that under Florida conditions it is usual to have some air movement which is apparently enough to replenish the CO_2 supply. It is possible during times of no air movement which are most likely to occur in early morning, late evening, or night, that the enclosures did allow slightly higher levels of CO_2 to accumulate than in the surrounding field. As more CO_2 would be released in the enclosures with the manure treatment, it may have had some effect. However, it should be pointed out that under field conditions it is almost impossible to vary one factor without varying the entire environment of the plant. The use of fiber glass walled or other open topped enclosures does not offer itself as a satisfactory way to increase the CO_2 level in the air since normal air movement and diffusion tend to minimize any desired CO_2 buildup. The use of any opaque and plastic material to wall in the enclosure would result in large changes in the light and temperature within such enclosures. Manure as a soil amendment not only affects the CO_2 but also produces marked chemical changes.

The chemical data from the soil and ear leaf at tasselling time are presented in Tables 3 and 4. The pH data for the soil samples were not significantly different but the remaining data showed that the manure increased calcium, magnesium, phosphorus and potassium significantly. The data in Table 4 show that the higher levels in the soil did not affect the amount of these elements and nitrogen in the corn ear leaf at tasselling time. This indicates that CO_2 or some other factor not measured caused the yield differences.

Table 5 contains yield data from the Klej fine sand. Minor elements in the absence of manure appeared to depress the yield from 118 bushels to 106 bushels per acre. Yields increased progressively with rates of manure

TABLE 3.—CHEMICAL DATA FROM SOIL SAMPLES AT CORN TASSELLING TIME FROM ARREDONDO FINE SAND.

Treatments*	pH	Acid Acetate soluble			
		CaO	MgO	P_2O_5	K_2O
Check	5.7	590	106	31	86
Enclosure	5.6	490	55	43	91
Enclosure + Chicken Manure	6.2	2390	298	472	263
Enclosure + CO_2	5.7	830	132	51	109
Chicken Manure	6.0	1900	253	347	329
L.S.D. 5%	N.S.	568	51	200	64
L.S.D. 1%		840	109	296	95

*Uniform treatments listed in preceding table.

TABLE 4.—CHEMICAL COMPOSITION OF CORN EAR LEAF AT TASSELLING TIME.

Treatment*	% N	% P	% K	% Ca	% Mg
Check	2.43	.31	.21	.41	.19
Enclosures	2.23	.27	.18	.38	.21
Encl. + CO_2	2.46	.29	.20	.38	.20
Encl. + Chicken Manure	2.27	.29	.20	.37	.20
Chicken Manure	2.41	.29	.22	.35	.18
	N.S.	N.S.	N.S.	N.S.	N.S.

*Chicken manure applied at 45 tons per acre. Uniform treatments listed in Table 2.

TABLE 5.—1961 YIELD DATA FROM CORN FERTILITY EXPERIMENT ON KLEJ FINE SAND AT SUWANNEE VALLEY EXPERIMENT STATION.

No.	Treatment*		Bus./ Acre	Yield data		
	5-10-15 lbs./A	Chicken Manure		Stalks/ Acre	Ears/ Stalk	Weight/ Ear
1	1000	0 (tons/A)	118	18800	1.03	.40
2	1000 (ME)	0	106	18200	1.06	.41
3	1000 (ME)	2	114	17600	1.12	.40
4	1000 (ME)	4	119	18200	1.11	.41
5	1000 (ME)	8	131	18000	1.10	.46
6	1000 (ME)	16	127	19400	1.10	.43
7	1000	8	130	18400	1.12	.44
8**	1000 (ME)	8	129	17800	1.13	.44
Ave.			117	1820	1.10	.42
L.S.D. 5%			17	N.S.	N.S.	N.S.
L.S.D. 1%			N.S.			

*All plots received 300 lbs./acre of nitrogen as a side dressing when corn was 35 days old.

**Also received 100 lbs./acre K_2O at time nitrogen side dressing was applied.

TABLE 6.—CHEMICAL DATA FROM SOIL SAMPLES TAKEN AT CORN TASSELLING TIME FROM EXPERIMENT ON KLEJ FINE SAND.

Treatment*			Soil analyses data					CO_2 Evolution
No.	5-10-15 lbs./A	Chicken Manure tons/A	pH	CaO	MgO	P_2O_5	K_2O	Mg/M²/hr.
				acid acetate extractable				
1	1000	0	6.5	1070	187	78	32	420
2	1000 (ME)	0	6.6	7.30	167	62	30	480
3	1000 (ME)	2	6.4	1320	149	108	62	480
4	1000 (ME)	4	6.7	1800	321	146	60	480
5	1000 (ME)	8	6.6	2470	186	184	99	460
6	1000 (ME)	16	6.7	2400	210	228	174	690
7	1000	8	6.6	1740	171	136	77	460
8**	1000 (ME)	8	6.6	2260	190	160	137	600
L.S.D. 5%			N.S.	1140	N.S.	17	50	N.S.
L.S.D. 1%				1630		24	72	

*All plots received 300 lbs. A of nitrogen as a side dressing when the corn was 35 days old.
**Also received 100 lbs. Acre K_2O at the time the nitrogen side dressing was applied.

up to the eight-ton level. There were no significant differences in stalks per acre, ears per stalk, or weight per ear. However, ears per stalk and weight per ear were usually higher for those treatments using manure. The soils data in Table 6 showed that the level of calcium, phosphorus, and potassium were increased significantly in the soil with manure. The magnesium and pH data were not different. The CO_2 data measured with the infrared gas analyzer (6) showed that the CO_2 evolution in milligrams per square meter per hour from the surface of the soil was not significantly different. Data were inconsistent. The measurements were made only once and at tasselling time. Earlier sampling may have shown a difference.

TABLE 7.—CHEMICAL COMPOSITION OF CORN EAR LEAF AT TASSELLING TIME.

Treatments*							
No.	5-10-15 lbs./A	Chicken Manure Tons/A	% N	% P	% K	% Ca	% Mg
1	1000	0	3.28	.36	.24	.37	.21
2	1000 (ME)	0	3.21	.36	.24	.36	.21
3	1000 (ME)	2	3.41	.34	.26	.36	.25
4	1000 (ME)	4	3.27	.35	.25	.36	.20
5	1000 (ME)	8	3.35	.33	.25	.38	.20
6	1000 (ME)	16	3.39	.32	.26	.36	.18
7	1000	8	3.44	.34	.26	.37	.20
8**	1000 (ME)	8	3.41	.34	.26	.39	.20
			N.S.	N.S.	N.S.	N.S.	N.S.

*All plots received 300 lbs./A of nitrogen as a side dressing when corn was 35 days old.
**Also received 100 lbs./A K_2O at side dressing time.

TABLE 8.—1961 CORN YIELD DATA AS AFFECTED BY ROW PATTERN AND FERTILITY FROM KANAPAHA FINE SAND NEAR GAINESVILLE.

No.	Treatment (lbs./A)* 4-12-12	N**	Rows Planted***	Bus/ Acre	Stalks M/A	Ears/ Stalk	Weight /Ear
1	0	0	xxoo	24	6.1	1.00	.29
2	200	40 (1)	xxoo	62	10.2	1.30	.33
3	600	80 (1)	xxoo	84	12.2	1.20	.40
4	600	80 (2)	xxoo	79	11.9	1.25	.37
5	600	80 (3)	xxoo	81 66	10.1 10.1	1.17 1.18	.40 .36
6	0	0	xxxx	34	16.2	.75	.22
7	200	40 (1)	xxxx	48	21.0	.86	.24
8	600	80 (1)	xxxx	82	26.7	.91	.36
9	600	80 (2)	xxxx	81	20.6	1.00	.39
10	600	80 (3)	xxxx	98 69	22.4 21.4	1.00 0.90	.33 .31
L.S.D. 5%				13	5.5	.29	.08
1%				18	7.6	.41	.10

*Treatments 1 through 5 have double rates of fertilizer applied on planted rows.
**Number in parenthesis represents number of equal increments. 1, 2, and 3 represent applications at knee high stage, knee high and waist high and knee high, waist high and just before tasselling respectively.
***Plots represented by xxxx are planted continuous. Plots represented by xxoo have two rows planted and two not.

The plant data in Table 7 indicated as before that the extra nitrogen, phosphorus, potassium, calcium, and magnesium contained in the soil as a result of the manure did not influence the uptake of these nutrients by the plant. The plant data suggests that something other than the nutrients listed, possibly CO_2 was improving corn yields.

Table 8 contains data from Kanapaha fine sand. The experiment compared five fertility treatments on corn with two planting patterns. The corn plants were the same distance apart in the rows for all treatments but when the stand with two alternately planted rows was calculated on an acre basis the stand was only half that of the solid planting yet the yields of the solid planting were very little more on the average. When the two rows were left out the ear weight was higher and there were more ears per stalk. This difference may have been due to a number of factors including light, temperature, moisture, and carbon dioxide. It has been estimated that 80% of the CO_2 required must diffuse into the field (8). The row pattern with the blank rows might alter all of the factors mentioned.

SUMMARY AND CONCLUSION

The role of CO_2 as a limiting factor in corn production under field conditions is discussed. Data are reported from 3 experiments in which several methods were used to try to increase the amount of CO_2 available to corn plants. In one experiment corn plants were grown in fiber glass walled enclosures 8 feet square and 8 feet high in which CO_2 was released from tanks at rates up to 1 liter per minute. This amount of CO_2 restored 15 bushels of the 16 bushel per acre drop in yield caused by the en-

closures. Chicken manure applied at rates of 45 tons per acre in the enclosures was almost as effective as the direct release of the CO_2, although neither increase was significant at the 5% level. Chemical analyses of the soil from this and another experiment where yield increases for chicken manure were significant at the 5% level showed higher phosphorus, potassium, calcium, and magnesium where chicken manure was applied while chemical data from corn ear leaf samples at tasselling time showed no differences in these elements or nitrogen indicating that possibly CO_2 or other factors not measured was causing the yield differences.

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Corn Yields and Incidence of Barren Stalks in an Experiment Using High Nitrogen Rates —A Progress Report[1]

JOHN G. A. FISKELL[2]

INTRODUCTION

Corn yields in Florida have continued to increase for many years. Many soils formerly thought to be capable of producing only 20 to 30 bushels per acre have recorded yields approaching 100 bushels. The farmer has been forced to seek better corn yields from his land because labor and machinery costs have increased greatly in recent years. Factors limiting yields have been investigated usually in the range below 100 bushels per acre. Factors limiting yields below 200 or even 300 bushels have not been delineated.

The objectives of the work reported herein were to study the effects of unusually high rates of nitrogen sources and their placement on corn yields.

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LITERATURE REVIEW

At any given population of corn plants per acre, Horner *et al.* (3) found only a limited yield response to added nitrogen at levels above 160 to 220 pounds per acre. As they had expected, there was less response to increased nitrogen at lower than at higher populations. Highest yield was 109 bushels. From their data, the optimum nitrogen level was 386 pounds at an optimum population level of 16,000 plants with irrigation. They used from 1400 to 2300 pounds of 0-10-20 as a broadcast application and 300 pounds of a minor element mixture in 0-10-20 in the row in addition to the nitrogen applied. They pointed out that the varieties Dixie 18 and Florida 200 used in the experiment were affected adversely by close spacings and that these hybrids were selected at relatively low plant populations. In an earlier study (7), these authors reported that the number of ears declined from an average of 1.8 at 4000 plant population per acre to 1.2 at 11,500 population. They measured a corresponding decline in ear weight from 0.424 to 0.364 pounds. Yields approaching 110 bushels were obtained in their plantings made on March 1 at spacings of 11 to 13 thousand. These yields were much higher than those planted 3 or 6 weeks later. The use of 160 pounds of nitrogen gave the highest yields at the highest population.

Investigation of the effect of diminished light at high corn plant population was reported by Prine (5). He suggested that in corn breeding the efficiency of utilization of light energy be considered. Where 123 bushel yields were obtained, he found a 6, 21 and 18% reduction in yield respectively where one third of the bottom leaves, the top third or one-half of the leaves along one side of the plant were removed.

In West Florida, Hutton and co-workers (4) concluded that fertility alone could not increase the corn yields beyond 110 bushels and that this was probably the limit for the variety tested. In North Florida, Thompson *et al.* (6) reported that, over a period of 12 years, corn yields averaged 65 bushels where 750 pounds of 8-10-8 fertilizer were used.

Deficiency of sulfur in the soil affected both nitrogen and sulfur content of oat plants uniformly fertilized, according to Harris (2). Where one or more elements were left out of the fertilization, he found the variations in plant composition of lupines were quite pronounced. Magnesium and phosphorus were less affected than potassium, calcium, nitrogen and sulfur. For corn, he reported that potassium and nitrogen were sensitive to lack of several elements in the fertilization of Blanton fine sand.

EXPERIMENTAL PROCEDURE

An area of Kanapaha-Ona soil complex located at the Horticultural Unit near Gainesville was chosen for this experiment. This soil was known to hold water well and had previously produced high corn yields. Equipment was available at the Unit to make beds sufficiently high to allow drainage of surface water after heavy rains.

The area had been in tomatoes and sweet corn the previous year. The residue of crabgrass was plowed under and the land disked several times in late February. The beds were made 68 inches apart using the tractor wheels to mark off and the Louisiana bedder to hill the soil. These were levelled to form a plateau type of bed. The plots were 47 feet long with

2 of the plateau beds per plot. Twelve such plots comprised each of the six replications. Part of the fertilization was made at this time with 6 treatments being involved. These are shown in Table 1 as being applied in the bed. The beds were reformed using a wider setting of the Louisiana bedder disks. These were scraped level to a width of 4 feet. Coker 71 seed was planted in 2 rows spaced 24 inches apart on the bed and a 7 inch-spacing was used in the drill to provide 25,000 plants per acre. At the same time 1000 pounds per acre of 2-12-12 fertilizer was banded 3 inches to the side and 3 inches deeper than the seed. The bed was sprayed with Simazine at the recommended rate to prevent weed and crabgrass emergence.

After the corn was about 6 inches high, the second fertilization was applied as a top dressing, as shown in Table 1. This was incorporated by a 6-inch sweep between the rows being careful not to move the soil too close to the corn. The bedder was used at this time to bring soil from the sides of the bed up to the corn, firm up the sides of the bed, and deepen the ditch between the beds as a provision for drainage.

When the corn was nearly 3 feet tall the final nitrogen top-dressing was applied. Four plots, shown as treatments 5, 6, 7 and 8 in Table 1, received 1220 pounds per acre of calcium nitrate[3] centered on the bed. These plots had received the dolomite and gypsum. Two other treatments with the fertilizer in the first bed received a heavier top-dressing applied to the center and sides of the bed, one receiving 2,180 pounds per acre of the calcium nitrate and the other 1,040 pounds of ammonium nitrate similarly. These are listed as treatments 11 and 12 in Table 1.

Nitrogen was provided in 4 ways at levels of 330, 490 and 630 pounds of N per acre. The treatments are summarized in Table 1.

The corn was sprayed once per week for several weeks with 1 pound of zineb and 2 pounds of wettable DDT per 100 gallons of water. In the early growth stages zinc deficiency was observed in several small irregular areas and magnesium deficiency in scattered locations. Sulfate of potash magnesium was applied at the rate of 200 pounds per acre placed on the bed when the corn was about 12 inches high. Ear-worm damage was controlled by dusting by hand with a 50:50 mixture of toxaphene and Nu-Z zinc dust. The latter was added as a possible correction for the zinc deficiency which did disappear about this stage of growth.

At tasseling time, the corn was irrigated by flooding the ditches between the rows. The water soaked in completely within one-half hour. A 2½ inch rain fell the next day. Moisture was not likely to be limited during this period of growth.

Harvesting was done in late August. The husked corn was weighed from 44 feet of each bed providing thereby two determinations per plot. Moisture was determined on the corn harvested from every 12 plots. Number of stalks, barren stalks and number of ears were counted on 12 external East and West plots and on 2 rows of plots or 12 in number further within the experimental area. Number of ears were counted on all plots. Shelling percentage was obtained. Yields were calculated to 15% moisture after the field yields were determined on the basis of oven-dry shelled corn.

Only one set of soil samples was taken and this was in May when the corn was nearly at full height. Seven cores, each to a depth of 6 inches, from the central part of the bed were composited per plot. Analysis for

[3]Consists of 14.0 percent N derived from $Ca(NO_3)_2$ and 1.5 percent N from NH_4NO_3.

TABLE 1.—EFFECT OF HIGH NITROGEN RATES, SOURCES AND PLACEMENT ON COKER 71 YIELDS.

Tr.	Total N	Fertilizer P_2O_5	Composition K_2O	Sources and Placement		Mean ear Weight	Yields*
	#/A	#/A	#/A			lbs.	bu./A
1.	350	120	120	NH_4NO_3	Mixed in the bed	0.433	115
2.	350	120	120	NH_4NO_3	95% top dressed	.443	123
3.	350	120	120	$NaNO_3$	Mixed in the bed	.428	112
4.	350	220	300	NH_4NO_3	Fert. top-dressed	.423	110
5.	490	220	300	NH_4NO_3	Mixed in the bed, 350#N	.424	125
				$Ca(NO_3)_2$	Top-dressed, 140#N		
					Gypsum, 780#/A		
6.	490	220	300	As above	As above except fertilizer top-dressed	.423	126
7.	490	220	300	NH_4NO_3	Mixed in the bed, 350#N	.453	131
				$Ca(NO_3)_2$	Top-dressed, 140#N		
					Dolomite, 1300#A		
8.	490	220	300	As above	As above except fertilizer top-dressed	.439	127
9.	630	220	300	NH_4NO_3	Mixed in bed, 350#N	.489	116
				NH_4NO_3	Top-dressed, 280#N		
					Fert. top dressed		
10.	630	220	300	$NaNO_3$	Mixed in bed, 350#N	.433	122
				NH_4NO_3	Top-dressed, 280#N		
					Fert. top dressed		
11.	630	220	300	NH_4NO_3	In mixed fert. in bed, 350#N	.431	133
				NH_4NO_3	Top-dressed, 280#N		
12.	630	220	300	NH_4NO_3	In mixed fert. in bed, 350#N	.432	135
				$Ca(NO_3)_2$	Top-dressed, 280#N		

*See Table 2 for differences between treatments. Yields are shown as the mean from 6 replications.

pH was in 1:2 soil to water ratio. Conductivity was measured with a Solu-Bridge and soluble salts calculated from a calibration curve using KCL. The flame photometer was used to determine soluble Ca, K and Na; Al was run by the method of Yuan and Fiskell (8).

RESULTS AND DISCUSSION

Although 350, 490 and 630 pounds of N were applied from the three nitrogen sources, the corn yields averaged 115.1, 126.7 and 126.8 bushels per acre for the four treatments at these respective rates. Within rates, placement of the nitrogen fertilizer was not significant. Effects of sources of the nitrogen were also not statistically significant. Additional phosphate and potash in treatment 4 did not affect yields over those in treatments 1 and 3. There were significant differences between treatments, as shown in Table 2. However, these differences were not large enough to be economic in terms of the fertilizer applied. It was obvious that some factor was causing a high variability within treatments. The coefficient of variation for each treatment, Table 2, was higher in some cases than others. For instance Treatment 2 had yields ranging from 91 to 164 bushels per acre whereas treatment 12 yields were from 120 to 145 bushels. The multiple range test, Table 2, showed several treatments yielded alike even though rates of nitrogen added were quite different.

Part of this variation occurred between replications. As shown in Table 2, the replication on the extreme East and West which are replications 1 and 6 were higher yielding than two out of four inner replications by Duncan's new multiple range test (1). Similarly, the four inner replications were alike. Therefore, conditions in the external rows were not really more favorable for yield production than those further within the experimental area.

At the time the soil was sampled the soluble salts were not high, Table 3. The pH was lower than was expected. This sampling showed that soluble Ca, K or Na did not account for most of the soluble salts present. From this, it was concluded that ammonium ion must be present. Calcium was not present in the soluble salts in proportion to the gypsum, dolomite or calcium nitrate added. Movement of soluble salts both laterally and

TABLE 2.—STATISTICAL INFORMATION ON CORN YIELD DIFFERENCES BETWEEN TREATMENTS AND REPLICATIONS

Treatments

Treatment No.	12	11	7	8	6	5	2	10	9	1	3	4
Coef. of Variation %	8	12	18	8	27	17	24	15	11	16	12	7
Means, bu./A.	135	134	131	127	126	125	123	122	116	115	112	110

Replications

Replication No.	1	4	6	2	5	3
Means, bu./A.	139	130	126	121	115	107

Note: Any two means underscored by the same line are not significantly different.
Any two means not underscored by the same line are significantly different.

TABLE 3.—SOIL ACIDITY AND SOLUBLE SALTS IN SOIL FROM SEVERAL TREATMENTS SAMPLED TWO WEEKS AFTER FINAL TOP DRESSING

Treatments[s]				Analysis of soluble salts							
No.	Sources of N	Rates of N	Calcium Added	pH	Cond.	Total	Ca^{2+}	K^+	Na^+	Al^{3+}	Cl^-
		lbs/A			mmhos	ppm	ppm	ppm	ppm	ppm	ppm
Outside of Plots	----------	------	---------	5.1	.05	------	0	10	0	0	VL
Between Plots	----------	------	--------	5.5	.11	100	4	19	5	1.8	M
1.	NH_4NO_3 b	350	Fert.b	5.0	.62	720	6	19	0	0	L
2.	NH_4NO_3 t	350	Fert.b	4.6	.67	760	44	30	0	1.2	L
3.	$NaNO_3$	350	Fert.b	5.7	5.9	540	0	14	210	0	VL
4.	NH_4NO_3 t	350	Fert.t	4.7	.85	890	49	85	2	.8	MH
5.	NH_4NO_3 b	350	Fert.b	5.2	.22	200	24	45	0	1.0	VL
	NH_4NO_3 t	140									
6.	NH_4NO_3 t	350	Fert.t	4.9	.72	660	139	38	0	1.2	M
	NH_4NO_3 t	140									
7.	NH_4NO_3 b	350	Fert.b	5.4	.21	190	20	40	0	0	VL
	NH_4NO_3 t	140									
8.	NH_4NO_3 t	350	Fert.t	5.4	1.10	920	44	106	5	0	MH
	NH_4NO_3 t	140									
9.	NH_4NO_3 b	350	Fert.b	4.8	.75	688	33	35	0	1.0	L
	NH_4NO_3 t	28									
12.	NH_4NO_3 b	350	Fert.b	5.2	.49	440	100	83	5	.2	M
	$Ca(NO_3)_2$ t	280	$Ca(NO_3)_2$ t								

[s]Symbol "b" refers to placement in the bed and "t" to top-dressing.

*Conductivity measured in 2:1 mixture of water and soil. Total salts calculated on the soil basis. Concentration of Cl⁻ present is designated in terms of the anion present and is labeled VL for very low, L for low, M for medium, and H for high.

vertically as well as the improbability of sampling exactly where these materials were placed probably resulted in dilution of the soluble salts at the locations sampled in the bed. These soil samples did not represent the salt content of the soil at any other time than that at the time the samples were taken. Therefore the variability between treatments and relationship to yields cannot be based on this one sampling. The range of values and the nature of the cations showed some relationship to the treatments applied.

The variability in the yields was directly resultant from the large range in the number of ears per plot. Weight of ear was not a significant factor between treatments. Nitrogen rates did not change the ear weight nor did the placement patterns. Very few stalks with two ears occurred anywhere in the plots. Many stalks, as tall as the yielding ones, were barren. The pattern of occurrence of these barren stalks was not a random one nor was it specific for any treatment. Upright stalks without ears occurred in clusters or in streaks. These patterns were more frequent where the early zinc deficiency was more prevalent. But all plots contained barren stalks which were as vigorous vegetatively as those that had an ear. The yield per plot resulted, of course, only from those stalks with ears. Therefore the yields were limited directly by the incidence of barren stalks. Just how serious this factor was is shown is Figure 1. An accurate count of stalks with and without ears was made on 12 plots in external rows and 12 plots within the area that had uniform stand free from blowing down and tangling. The percentage of barren stalks was very significantly correlated

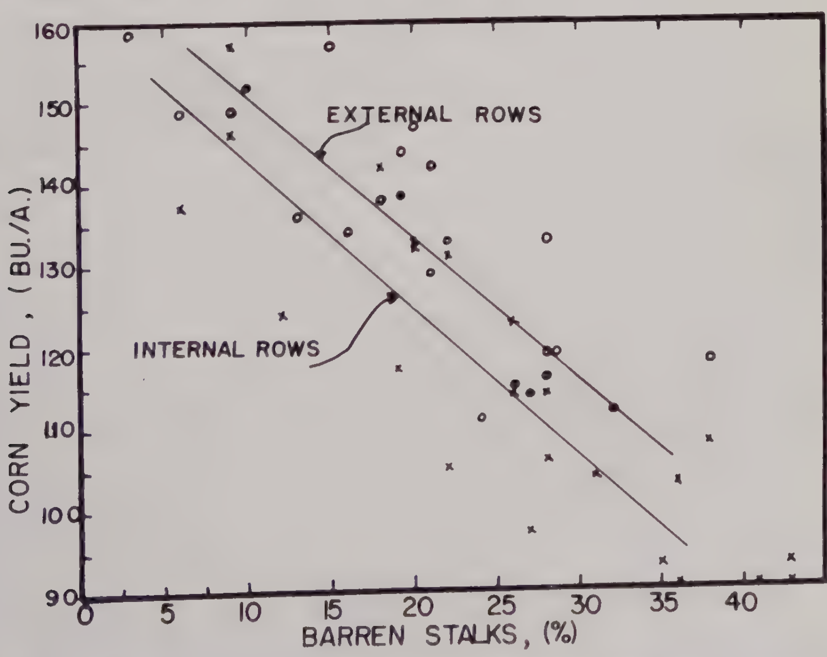

Fig. 1.—Relationship of the percent of barren stalks to yields for 12 external row plots (symbol "O") has a correlation coefficient of $-.824$ with a very significant t value of 6.79. Corresponding relationship for 12 internal row plots (symbol "x") is $r = -.887$ with $t = 8.31$, also very significant.

with the corn yields and the correlation was statistically alike for both external and internal rows. On the area, all stalks tasselled and silked uniformly with most stalks at the early stage of ear formation showing promise of two ears. Some factor therefore caused certain of these ears to be either sterile or incapable of seed production. Such factors as light, genetic factors, fertilization and pollination must be considered as uniform within plots and hence did not explain why patterns of barren stalks occurred. The data in Figure 1 included treatment effects.

Possible clues, other than the zinc deficiency, were provided in the ears that developed. There was a tendency for many ears not to fill out fully. This could be explained partially on the basis of pollination because gaps existed in some rows, and in a very few cases only a few scattered kernels occurred per ear. Boron deficiency must also be suspected because boron is known to be a factor in corn ears filling out as it is a known factor in other seed production, notably clover. Leaves did not exhibit any chlorosis or die-back attributed to minor elements or to salt injury. Symptoms of nutritional disorders of the type leading to barren stalks were not obvious. The present experiment was not designed to test the role of minor elements in corn yields. However, past experiments in this and other areas have not shown yield response by field corn to minor elements tested at much lower fertility levels.

Certainly unless the causal factors for decline in the number of ears per stalk with increased stands and for barren stalks are corrected, high nitrogen fertilization cannot increase corn yields economically.

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Response of Corn Hybrids to Dense Planting and High Fertilization

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Considerable interest in high corn production through heavy fertilization, close spacing, and irrigation has developed in recent years. Several experiment station workers in North Florida have obtained yields in the 120 to 140 bushels per acre range. However, this general yield level has not been surpassed regardless of the treatments used. The apparent ceiling of about 130 bushels per acre raised the question of breeding corn hybrids that will respond to intensive cultivation more favorably than those presently available, which were developed under relatively low population and fertility conditions.

REVIEW OF LITERATURE

There is evidence to support the concept of differential response of hybrids to close spacing and high frtilization. Lang *et al.* (2) reported a striking example of interaction between hybrids and population rates. One single cross (Hy2 x Oh7) reached maximum production at 20,000 plants per acre, while the yield of another (Wf9 x C103) declined markedly at populations over 12,000. Yields of these 2 hybrids were essentially equal at 4,000 and 8,000 populations, but at 20,000 Hy2 x Oh7 yielded 31 bushels per acre more. Stinson and Moss (4) found that artificial shading has the same effect as dense planting. Hybrids known to be tolerant of close spacing showed less yield reduction, fewer barren plants and less reduction in ear size than an intolerant group when grown in the shade as compared with full sun. They concluded that the former were more efficient in the use of light than the latter. Sowell *et al.* (3) found that the high grain yield of the mutant "compact," compared with its normal counterpart (Hy), at high populations was due to the termination of vegetative growth at an earlier stage of development than in normal plants. Chinwuba *et al.* (1) reported an interaction between pollen sterility *vs* fertility and high populations of corn. At 6 inch spacings in 38 inch rows, a male sterile hybrid produced 41% (22 bushels) more than the fertile counterpart, while at 18 inch spacings there was a yield difference of only 3% in favor of the sterile hybrid. Detasseling a fertile hybrid gave similar results but the difference was not as large (25% more grain for the detasseled than for the non-detasseled fertile hybrid at the 6 inch spacing). These results indicate that the energy required to produce pollen becomes critical in dense plantings, and that higher yields at very close spacing may be obtained with hybrids that have a portion of the plants male sterile. This could be achieved by using only one fertility-restoring line in the pollinator of double crosses produced with the use of male sterile seed parents.

One may conclude from the results cited above that corn hybrids with similar grain yield potentials at normal spacings may differ markedly in

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performance at high populations. The main factor causing this hybrid x spacing interaction seems to be a difference in capacity to utilize light efficiently. Other factors include (1) cessation of vegetative growth at flowering time so that all energy is directed to the ear, and (2) variation in energy devoted to pollen production. Hybrids may also vary in capacity to utilize nutrients and CO_2 under the highly competitive conditions found in dense plantings, but there appears to be no published data on these factors. The yield component most affected by close spacing is number of ears per plant. Hybrids intolerant of close spacing are apt to produce a high proportion of barrn plants, while tolerant hybrids produce relatively few barren plants at close spacings.

COMMERCIAL VARIETIES FOR FLORIDA

Few tests of commercial varieties have been made at high fertility and close spacing in Florida. However, the results of two such tests, one at the West Florida Station in 1959 and one at the Main Station in 1961, indicate some interaction between varieties and treatment. Five hybrids were included in both close spacing tests as well as in the regular variety tests. Dixie 18 was the highest yielding hybrid under high population and fertility, but was no better than the others in the regular tests (Table 1). There was good agreement between the two tests at high populations. These results indicate that Dixie 18 responds somewhat more favorably to intensive treatment than the others.

DISCUSSION

The corn hybrids grown today are the products of thousands of generations of selection, both by nature and by man. During this period environmental conditions were certainly much different from the high population, high fertility situation we now have in corn-growing contests. It appears very likely that selection at high fertility and close spacing for several

TABLE 1.—COMPARISON OF COMMERCIAL CORN HYBRIDS UNDER CONDITIONS OF "NORMAL" AND "HIGH" POPULATIONS AND FERTILITY LEVELS.

	BUSHELS PER ACRE			
			Individual tests at high levels	
Hybrid	Normal level average[1]	High level average[2]	Gainesville 1961	Jay 1959[3]
Coker 67	81.3	103.5	113	94
Coker 811	81.1	100.5	108	93
Florida 200	80.0	107.5	120	95
Dixie 18	79.6	112.5	122	103
Coker 71	77.0	96.0	105	87

[1]"Normal" levels were spaced at 8,000 to 10,000 plants per acre in different tests. Average of 18 tests over 3 years.

[2]"High" levels were spaced at 18,000 plants per acre at Gainesville in 1961 and 13,700 plants per acre at Jay in 1959.

[3]Test conducted by Dr. M. C. Lutrick, West Florida Station.

generations of breeding would result in hybrids better suited to this type of environment than those now available in Florida. However, progress in developing higher-yielding hybrids probably would not be as rapid as one might hope, because strong selection pressure must also be applied for lowered ear height and increased stalk strength. Experience has shown that if these characters are ignored and selection is for yield only, ear height becomes progressively higher and lodging progressively worse. Presently available hybrids, while satisfactory at spacings of about 8,000 plants per acre, become much too tall and lodge badly when spaced at 15,000 or more plants per acre.

During the past 12 to 15 years, there has been a marked trend toward heavier fertilization and closer spacing of corn in Florida. This has been reflected in an increase in average yield per acre from about 10 bushels to over 30 bushels per acre in the state during this period. In view of the rapid population increase and continued loss of farm land to urban development, the trend toward more intensive corn culture is likely to continue. More and more people will have to be fed on less and less land. In 10 years there will probably be a much greater demand than now for corn hybrids which will respond to heavy fertilization and dense planting. A breeding program to develop such hybrids should be started now.

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SYMPOSIUM: NITROGEN

C. F. ENO, *Presiding*

Nitrogen Transformations in Soils[1]

FRANKLIN E. ALLISON[2]

There has been an extremely keen interest in recent years in what happens to nitrogen in soils, especially to various kinds of fertilizer nitrogen. This interest is due largely to the tendency to use higher and higher rates at correspondingly higher costs per acre, and to the realization that, regardless of rate of addition, seldom is more than 60% of this nitrogen recovered in the harvested crop. It is only by knowing the fate of nitrogen in soils that a higher efficiency in its use can be realized.

In the present discussion of this broad subject of nitrogen transformations in soil emphasis will be placed for the most part on some of the phases that have been of most interest in recent years, and also on the researches with which the author has had most direct contact.

SOURCES OF NITROGEN FOR CROPS

The chief forms of nitrogen that are directly assimilated by plants are ammonia and nitrate. Nitrite, formed as an intermediate in the oxidation of ammonia to nitrate, is also assimilated but is toxic at comparatively low concentrations. Under optimum soil conditions it is usually present only in traces but heavy applications of ammonia fertilizers sometimes retard its oxidation to nitrate and allow it to accumulate. Some simple forms of organic nitrogen, such as urea and amino acids, may also be utilized directly. Legumes that are nodulated with effective bacteria can, of course, grow normally on atmospheric nitrogen.

RELEASE AND IMMOBILIZATION OF SOIL NITROGEN

The chief source of nitrogen for crops under most farming conditions is the soil. The nitrogen compounds in soil are rather resistant to biological attack since soil organic matter is itself a residual material. Soils contain hundreds of species of bacteria and fungi that continually, but slowly, decompose the carbon compounds to obtain their energy supply. Some of the nitrogen is used by the microorganisms for their own growth; the remainder is released as ammonia.

Oxidation of the released ammonia, in the absence of plants, usually proceeds as fast as it is formed unless the soil is very acid. The lower pH limit for oxidation is about 4.2 to 4.5; the optimum is pH 7 or above. Ammonia is oxidized to nitrite chiefly by *Nitrosomonas*, and the nitrite to nitrate by *Nitrobacter*. A few heterotrophic organisms, notably *Aspergillus flavus*, have been shown (16) to convert organic nitrogen into nitrate under

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laboratory conditions, but there is no proof that such organisms are important in field soils.

When soils are incubated in the laboratory under optimum conditions usually about 1 to 2% of the total nitrogen is converted into nitrates within 3 weeks. Thereafter the rate of nitrogen release usually decreases gradually. In such a study (5) of 30 soils taken from long-time experimental plots located at Mandan, North Dakota, the per cent of the total soil nitrogen that accumulated as nitrates in 3, 6, 12 and 20 weeks were 1.6, 2.4, 3.7 and 4.7, respectively. The pH of these soils ranged between 6.1 to 7.3 with an average value of 6.7. In more acid soils, common to the humid region, the rate of release of soil nitrogen is usually lower. In all such nitrification studies there is a marked tendency for nitrate production to be closely and directly correlated with the total nitrogen content of the soils, if they are of similar type and from the same region (5).

The net release of nitrogen from soil organic matter under field conditions is of course much less than observed in these laboratory experiments. This is due in part to the absence of sieving and drying of soils in the field, and to less satisfactory conditions for decomposition. It is also due to the fact that field soils are cropped; and cropped soils do not give a measure of total nitrogen release, but only of net release. The crop is continually adding available carbohydrates that tie-up a portion of the nitrogen being released. This tie-up occurs as a result of root excretions, sloughed-off cells, and finally the unharvested crop residues. The work of Goring and Clark (8) shows this effect of crop very strikingly.

It has been shown repeatedly (14, 15, 18) that a cultivated crop, such as corn, removes about 2 to 3% of the soil nitrogen in the plowed layer during a growing season; a small grain crop removes about 1%; and a non-legume sod even less. These values are affected by recent history of the soil, intensity of cultivation, pH, and various other factors connected with farm management.

IMMOBILIZATION AND RELEASE OF NITROGEN IN THE PRESENCE OF PLANT MATERIAL

Nitrogen immobilization or mineralization following incorporation of plant materials into soil depends largely on the carbon-nitrogen ratios of the added substances if they decay readily and fairly completely (12). Obviously, the carbon-nitrogen ratio means little if the material is high in lignin or for other reasons is very resistant to biological attack. The work of Rubins and Bear (13) shows this very clearly.

When a readily decomposable plant material, such as straw, is added to soil the rapid and intensive biological activity that follows results in a marked immobilization of available nitrogen. Estimates of the amount of nitrogen needed for this initial decomposition usually vary between about 1.2 and 2.0% (carbon-nitrogen ratio = 33 to 20), based on the original weight of dry plant material added. Greenhouse experiments conducted by Pinck *et al* (12) showed nitrogen requirements of 1.2 (carbon-nitrogen ratio =35) in one experiment lasting 14 weeks, and 1.56 (carbon-nitrogen ratio = 27) in another lasting 6 weeks. In such experiments it is likely that the maximum nitrogen requirement was not obtained.

Laboratory results (4) obtained recently at Beltsville show a very close correlation between nitrogen immobilization and rate of CO_2 evolution during the decomposition of wheat straw. The maximum nitrogen re-

quirement in these experiments was reached in about 20 days and amounted to 1.6 to 1.8% of the initial dry weight of the straw. Subsequently, there was a slow release of the immobilized nitrogen. At the end of 75 days all of the nitrogen above 1.08% has been converted into nitrates. During this period about 65% of the original plant carbon escaped as CO_2. The carbon-nitrogen ratio of the residual material was therefore 13, which is near that of soil organic matter. This residual material doubtless consisted chiefly of microbial cells, lignin, and their decomposition products.

In somewhat similar laboratory experiments, using sucrose and ammonium sulfate additions to soils, Winsor and Pollard (4, 17) observed maximum immobilization in 2 days. In some of the soils this amounted to 3.7 to 4.4% of the original weight of sugar added. Since the sucrose was quickly and completely available the residual material, which was almost wholly microorganisms, had a carbon-nitrogen ratio of about 6.2. Within 16 days following maximum immobilization about a third of this nitrogen had been released in available form. These immobilization experiments using straw and sucrose emphasize the importance of (a) composition of the original carbonaceous material, (b) environmental conditions that affect rate of decay, and (c) the importance of the time allowed for decay to proceed before nitrogen tie-up is measured.

When fresh plant materials that are comparatively high in nitrogen, such as alfalfa hay, are added to soils, the rate of release of CO_2 is about the same as from a material, such as straw, that is supplied with outside nitrogen. Most of the nitrogen in high-nitrogen plant materials above the 1.5 to 1.8% level, based on the initial dry weight, is quickly made available for crop use. The remaining nitrogen is released at an ever-decreasing rate over the subsequent months and years as the carbon with which it is combined is released as CO_2

Is it possible to avoid this rapid loss of about two-thirds of the carbon of the plant materials by adding a large excess of available nitrogen? The answer is definitely no (2). Under field conditions the addition of abundant nitrogen year after year will tend to maintain the soil organic matter at a slightly higher level, but this is because the added nitrogen increases crop yields, and more carbon is returned to the soil in the plant residues.

EFFECT OF PLANT ADDITIONS ON DECOMPOSITION OF NATIVE SOIL ORGANIC MATTER

There has been much interest during the past 15 years, since the initial publication of Broadbent and Norman (6), in the effect of additions of green manures and other plant materials on the release of carbon and nitrogen from native soil organic matter. Most workers in this field have shown by isotopic techniques that when such materials are added to soils there occurs an increased oxidation of the native organic matter during the period of greatest carbon-dioxide evolution from the added plant materials. This observation might well have been predicted since the added materials undoubtedly greatly increase microbial enzyme production.

Pinck *et al* (11) found that the effect of fresh plant materials on soil carbon content was too small to be measured by ordinary chemical methods. Later, however, Pinck (unpublished data) observed some increases in oxidation of native soil carbon when he used the C^{14}-tracer technique. Frequently, the increases during the first two or three weeks were followed by decreases. The over-all increase, if any, after an extended period of time

is likely to be too small to be of much practical importance. Certainly no one should hesitate to turn under green manures or crop residues because of any possible detrimental effects on soil organic matter. If such plant materials are not added to cultivated soils, organic matter will certainly not be maintained.

EFFECT OF ADDITIONS OF FERTILIZER NITROGEN ON UPTAKE OF SOIL NITROGEN BY CROPS

Recent research (9) using N^{15}-labeled fertilizers, has brought to light an interesting finding, namely that in nitrogen-deficient soils the uptake of soil nitrogen by crops increases as the rate of addition of fertilizer nitrogen increases. In greenhouse experiments with two subsoils fertilized with N^{15}-tagged ammonium sulfate at varying rates, the uptake of soil nitrogen by Sudan grass was about 3.5-fold greater with 400 pounds of added nitrogen than with none. This is perhaps contrary to what might have been expected. The explanation probably depends to a minor extent on the larger root systems and their potential feeding capacities produced by the higher rates of nitrogen. The major effect, however, undoubtedly involves the microflora in the rhizosphere. Growing plants continually add energy sources to soil in the forms of excretions from the roots, sloughed off cells, and root fragments. In a nitrogen-deficient soil such materials would have comparatively wide carbon-nitrogen ratios. As the rhizosphere microflora decompose such materials, these organisms would assimilate nitrogen as it is released from the soil. With an increase in fertilizer nitrogen the carbon-nitrogen ratio of these materials would be narrower and the microorganisms would tie-up less of the released soil nitrogen.

RECOVERY OF FERTILIZER NITROGEN IN THE GREENHOUSE AND IN THE FIELD

When crops are grown in greenhouse pots using moderate rates of nitrogen, most of the added nitrogen can usually be accounted for if optimum conditions are maintained. Not only must excess acidity and waterlogging be avoided but the soil should have a good nitrifying capacity so that nitrite will be oxidized to nitrate as rapidly as it is formed.

Under ideal greenhouse conditions, if tagged fertilizer nitrogen is added and a small grain crop is grown, perhaps 50 to 65% of the nitrogen will be recovered in the tops and another 10 to 12% in the roots if the soil used is low in organic matter. Most of the remaining nitrogen should be found in the soil in organic form, partly as unrecovered fine roots and partly as immobilized nitrogen in the microbial cells. Any nitrogen not recovered in the crop and soil must have escaped as gas.

Under field conditions, such an experiment cannot be conducted with accuracy because of natural soil variations, and because of errors in sampling and analysis of large masses of soil. The determinations of nitrogen recovery in the harvested crop can be accurate, of course. Much available data of this type shows that usually the recoveries in crops grown in the field are less, and often much less, than those obtained under greenhouse conditions. Such low recoveries may be due in a minor way to the greater tie-up of added nitrogen by the more extensive root systems of field-grown crops, and by the associated rhizosphere microorganisms. More important, however, are the losses of nitrogen by leaching and as gases.

LOSSES OF NITROGEN BY LEACHING

Leaching losses of nitrogen from soils in the humid region vary widely with soil, rainfall distribution, and cropping system. Quantitative data on such losses under field conditions are meager. Present information indicates that these losses, under conditions of good farm management, are not likely to be a major factor during most of the growing season except in very sandy soils and in years or regions of unusually high rainfall. During the winter period, when rainfall usually exceeds evapotranspiration by a considerable margin, most of the nitrate nitrogen present may be lost. Since nitrification proceeds at a greatly reduced rate during the colder months, the nitrate removed by leaching during the winter and early spring is likely to be chiefly the nitrate formed during the fall and early winter. This emphasizes the desirability of using a farming system that avoids the accumulation of nitrates at the end of the growing season. Almost any growing crop is effective in keeping leaching losses to a minimum.

LOSSES OF NITROGEN BY VOLATILIZATION

Nitrogen may be volatilized from soils in the forms of ammonia, molecular nitrogen, and oxides of nitrogen; and in small amounts from plants in organic form. There are several mechanisms of loss which will be reviewed briefly. Most of these mechanisms are fairly well understood but the magnitude of the losses under various field conditions is still largely unknown.

Ammonia volatilization is favored by an alkaline reaction, high temperature, and drying of the soil, especially if the ammonia is at the soil surface. The loss is very small, even in alkaline soils, if the ammonia is incorporated into the soil.

Molecular nitrogen and nitrous oxide may be formed by reduction of nitrites and nitrates where the soil is deficient in oxygen. This process, commonly designated as denitrification, may occur in waterlogged soils or wherever aeration is unsatisfactory. Recent work has shown that such losses of nitrogen can occur even where some oxygen is present. The bacteria that produce these gases use atmospheric oxygen preferentially for respiration but can obtain their oxygen from nitrites and nitrates if necessary. In this case the nitrogen and nitrous oxide gases are released as by-products of bacterial metabolism. Since denitrification starts with oxidized forms of nitrogen, such losses can be minimized by use of a farm management system that avoids having much nitrate present when poor soil aeration is a strong possibility.

Molecular nitrogen may also be formed by chemical reaction according to the so-called Van Slyke reaction. This involves the reaction of nitrous acid with a reduced form of nitrogen, such as ammonia or amino acids. The nitrogen gas evolved is derived in equal proportions from the two reacting substances. Research (3) conducted at Beltsville a few years ago showed that this reaction is not likely to occur in soils to any appreciable extent. Nitrous acid is so unstable in an acid medium that much of it is likely to decompose into oxides of nitrogen before it has an opportunity to react with other substances.

Nitrogen gas, ammonia and nitric oxide, may also form in soil as decomposition products of ammonium nitrite. Fortunately, this compound probably does not form to any marked extent under most soil conditions.

Presumably it could form where the ammonium concentration, or possibly the pH, is such as to cause a delay in the oxidation of nitrite. Indian workers have emphasized the importance of ammonium nitrite as an intermediate in gaseous losses of nitrogen from soils, but quantitative data are lacking.

Loss of gaseous nitrogen as NO through the chemical decomposition of nitrous acid is now receiving increased attention. The instability of nitrous acid in an acid medium has long been known, but little attention was given to this fact in soil studies in the past because there was little evidence for the presence of much nitrite in soils. Now that the use of heavy applications of nitrogen fertilizers is a common practice, nitrite-nitrogen in soils must be considered as a likely possibility. Fortunately, the NO released when nitrous acid decomposes, is readily absorbed by soils and most of it is likely to be oxidized to nitrate rather than to escape to the atmosphere.

A few nitrogenous organic substances, such as hydrocyanic acid and amines (1) may be exuded from plants and a portion of the nitrogen escape by volatilization. Such losses are believed to be small.

GENERAL REMARKS

This discussion emphasizes the many and varied things that can happen to soil and fertilizer nitrogen. It may migrate back and forth between the organic and inorganic forms readily. In doing this not only may some of the nitrogen be made temporarily unavailable but there are many opportunities for loss in the drainage waters and to the atmosphere. Low recoveries of nitrogen in the crop under many conditions are therefore not surprising.

In recent years much emphasis has been placed on gaseous losses of nitrogen and perhaps too little on residual soil nitrogen. As pointed out above, immobilization may often tie-up much nitrogen, perhaps 10 to 20% of that added as fertilizer, depending upon rates of application and cropping system. Most of this nitrogen, not lost by leaching during the following winter, will be available for the use of subsequent crops. In the years prior to 1930, when fertilizers were seldom used at rates higher than 50 pounds of nitrogen per acre, it was commonly believed that the second-year residual effects of such applications were negligible. At least it was difficult to show otherwise. Recent researches (10) with the higher rates have shown that this is not necessarily true, at least not under the better systems of farm management. If the climate and cropping system are such as to favor rapid mineralization of the immobilized nitrogen at a time when there is no crop present to utilize the nitrates being formed, then, of course, there may be little recovery of this residual nitrogen.

Questions are often asked as to the efficiency in terms of nitrogen recovery in the crop of various sources of commercial fertilizer nitrogen. Obviously, there can be no stock answers to such queries. Each situation must be considered individually. For example, nitrate, which usually gives high recoveries, might be a poor nitrogen source to use on a very sandy soil in a region of high rainfall. Similarly, ammonia, which is an excellent nitrogen source, may show poor crop response when used on a base-deficient soil; and also poor nitrogen recovery if used under conditions where nitrification is retarded (7). Organic nitrogen sources that may sell for premium prices, usually show low nitrogen recoveries because of delay in

release of the nitrogen and increased opportunities for leaching. In general, it may be stated that all of the common readily available commercial sources of nitrogen are likely to be nearly equally efficient if they are properly applied, and if due consideration is given to their individual properties. Highest efficiency may be expected if they are applied at a time, and at such a rate, that the crop can use them rapidly and completely.

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Nitrogen Transformation and Utilization in Plants

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The problem of the utilization of different forms of nitrogen by plants has interested agrochemists and plant physiologists for many years. For well over 150 years, nitrogen has been recognized as being of major importance in crop production. Various forms of nitrogen-containing materials have been shown to be utilized by plants. In the case of sulfur and phosphorus it has been shown that these elements must be in a certain state of oxidation before plants utilize them. With nitrogen however, oxidized and reduced forms, in addition to molecular nitrogen, appear to be utilized by some plants under appropriate conditions. The different pathways of these compounds in plant metabolism are being actively investigated at the present time in many laboratories throughout the world. This paper will attempt to give a brief review of some of the current research on nitrogen metabolism in plants.

A more detailed account of current research in this field will be found in the Symposia of the Society for Experimental Biology, Number XIII "Utilization of Nitrogen and its Compounds by Plants" by Steward, *et al.* (1959).

Table I. Webster (1959), shows the utilization of various forms of nitrogen by plants. It can be seen that the majority of the higher plants can utilize organic nitrogen, ammonia nitrogen, and nitrate nitrogen. Most of the discussion to follow will be concerned with the utilization and transformation of these forms of nitrogen in green plants.

TABLE I.—UTILIZATION OF VARIOUS FORMS OF NITROGEN BY PLANTS
(from Webster, 1959)

Group	Organism	Organic nitrogen	Ammonia nitrogen	Nitrate nitrogen	Molecular nitrogen
I	Some fungi (Endomyces Phycomyces); some bacteria; and some species of Euglena	X			
II	Some fungi (Mucor, Rhizopus); some bacteria	X	X		
III	Most bacteria, fungi, algae and higher plants	X	X	X	
IV	Some bacteria and blue-green algae	X	X	X	X

Early studies on the ability of plants to utilize organic forms of nitrogen have been viewed with suspicion because of the lack of experimental conditions necessary to ensure aseptic growth. The presence of microorganisms in the growth solution would break down the organic forms of nitrogen to ammonia and nitrate which could then be assimilated by the plants. There have been, however, a number of studies carried out under aseptic conditions and these have shown that plants can utilize a variety of different forms of organic nitrogen—amino acids, imines, amides, as well as more complex organic molecules. The studies of Ghosh and Burris (1950) are

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of interest in this connection in that they investigated the uptake of amino acids by clover, tomato, and tobacco plants. With clover alanine, arginine, asparagine, glutamic acid, glycine, histidine, isoleucine, leucine, lysine, and phenylalanine were better nitrogen sources than ammonia. With the tomato plant alanine, asparagine, arginine, aspartic acid, glutamic acid, glycine, histidine and proline were better nitrogen sources than ammonia. Aspargine, isoleucine, leucine, lysine, and phenylalanine which were good sources of nitrogen for clover were inferior nitrogen sources for tomato. With tobacco all of the organic nitrogen sources tested were poorer nitrogen sources than either ammonia or nitrate. These studies indicate that plants vary greatly in their ability to utilize organic nitrogen.

Steinberg (1952) described a condition in tobacco known as "frenching" which appeared to be related to the accumulation in the tissue of high concentrations of several amino acids—L-isoleucine and L-alloisoleucine. The symptoms of this condition are characterized by chlorosis and a reduced, strap-like leaf. Woltz and Jackson (1961) showed that a physiological disease of chrysanthemum known as "yellow strapleaf" was similar to the "frenching" condition of tobacco. Both disorders could be brought about by growing plants in high concentrations of certain amino acids. Yellow strapleaf of chrysanthemum could be produced by the application of DL-alloisoleucine, D- and L-isoleucine, and L-leucine. Frenching of tobacco, according to Steinberg (1952), was produced by L-isoleucine and L-alloisoleucine. L-leucine was effective on *Nicotiana rustica* but not with *N. tabacum* (Maryland Medium Broadleaf and Havana 142). The results indicate that certain isomers of leucine and alloisoleucine may be instrumental in producing the symptoms associated with these two disorders. Woltz and Jackson also investigated the symptoms produced by the application of DL-isoleucine plus DL-alloisoleucine to the root zone of a number of different plants. Symptoms similar to the yellow strapleaf condition were found in 15 of 22 genera treated. Nothing is known of the metabolic disturbances that occur within the plant under the influence of high concentrations of amino acids.

Virtanen and Linkola (discussed by Meittinen, 1959) reported that pea plants were drastically modified when grown in a nutrient solution containing less than 0.2% DL-alanine. The plants showed an increased branching, reduced leaves, and tufty roots. Subsequent work showed that only the D-form of alanine was toxic.

Waris (1959) has also studied the morphogenetic effects of amino acids on plants. Seeds of *Oenanthe aquatica*, an aquatic member of the Umbellifereae, were germinated and placed in a solution containing 0.1 - 0.4% glycine and 1% sucrose. After several months of normal growth, the seedlings became quiescent. However, small groups of cells became detached from the root tips and developed into simple plants with strap-shaped leaves and reduced roots. These simple plants were called "neomorphs" by Waris. When they were transferred to a nutrient solution containing sugar but no glycine, the plants reverted to their normal growth habit. Waris believes that the amino acids are very closely connected with differentiation in plants. Differentiation depends on equilibria between the many substances involved in metabolism. Thus there may be a competitive interaction between various amino acids, between various sugars, and between these two groups of compounds. Such interactions are probably not restricted to the sugars and amino acids but also to other active metabolic compounds.

In addition to these interactions and antagonisms between cell metabolites there is the fact that many of the important cell metabolites may be restricted to very localized areas within the cell. We can no longer consider the cell as a bag filled with a watery solution containing sugars, amino acids, fats, etc. The modern picture of the cell (Figure I) shows a very highly organized structure containing numerous organelles—nucleus, plastids, mitochrondria, microsomes, endoplasmic reticulum, etc. Various metabolic functions are localized within these structures. Thus the respiratory enzymes and reactions are localized in the mitochrondria, photosynthesis is localized in the chloroplasts, protein synthesis appears to be localized in the microsomes and in the chloroplast. Modern biochemistry has shown that the metabolism of carbohydrates, proteins, and fats are related through a number of common pathways so that interactions and antagonisms are bound to occur when an imbalance occurs in one or more of the common metabolites. Some of these inter-relationships are shown in Figure 2. Many

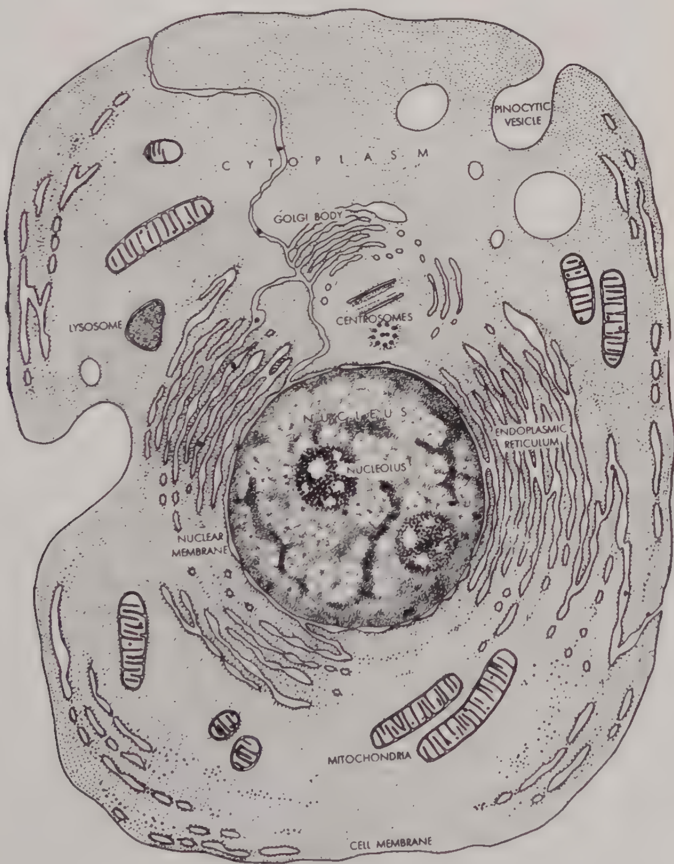

Fig. 1.—Modern Diagram of a Typical Cell. This is based on what is seen in electron micrographs. The mitrochrondria are the sites of the oxidative reactions that provide the cell with energy. The dots that line the endoplasmic reticulum are ribosomes: the sites of protein synthesis. The chloroplasts, not shown in this figure, are the sites of the photosynthetic reactions. (Figure reproduced by permission of the Scientific American.)

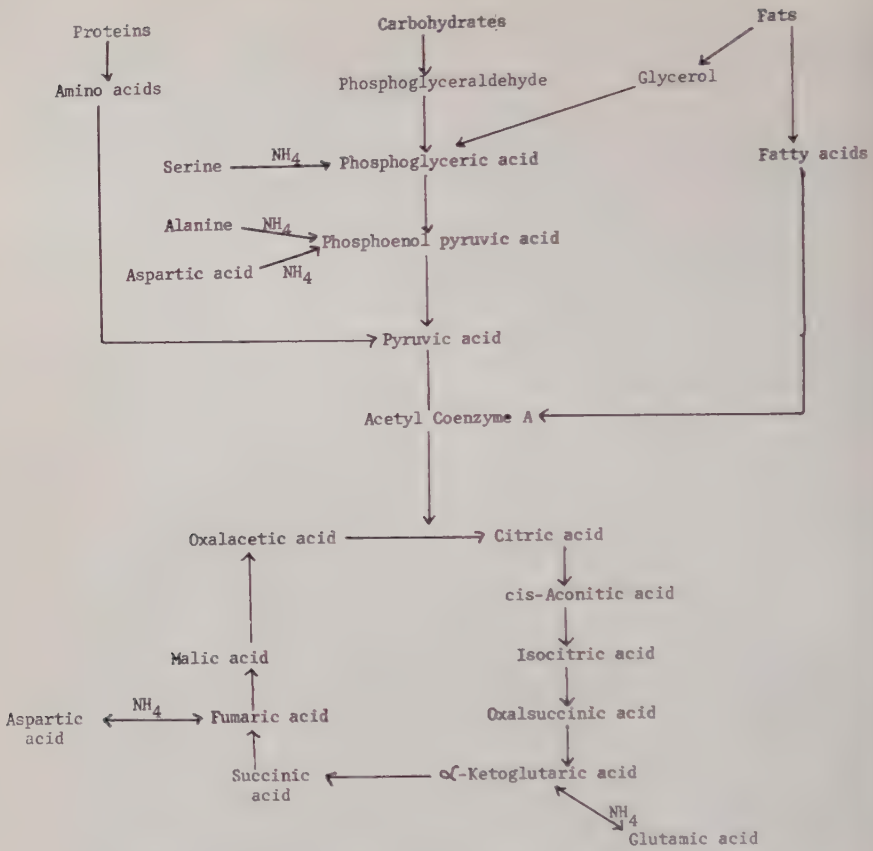

Fig. 2.—Inter-relationships of some common metabolites.

of the reactions are reversible and it can be seen that there are a number of common intermediates between the proteins, carbohydrates, and fats.

Ten years ago it would have been impossible to discuss or describe the fate of individual amino acids and other nitrogenous compounds in plant tissue. The details of intermediary metabolism as worked out by biochemists have clarified this situation. No longer is it necessary to discuss soluble-N, insoluble-N, amino-N or Kjeldahl-N. New analytical methods and techniques involving chromatography, electrophoresis, enzymology, and isotopes enable the modern investigator to pinpoint individual nitrogen containing compounds.

There have not been many studies carried out using the new analytical methods to study the nitrogen transformations within plants. The most extensive work is that of Steward and associates at Cornell University. Much of this work is summarized in a review paper entitled "Nutritional and Environmental Effects on the Nitrogen Metabolism of Plants" by Steward *et al.* (1959). In these studies, plants (*Mentha piperita*) were grown under controlled conditions of environment and nutrition and the soluble nitrogen fraction of the leaf, stem, and roots analyzed for individual amino acids, amides, and certain other nitrogenous constituents. It is not possible

to go into all the details of the analytical work but certain basic observations may be made. The individual amino acids that made up the soluble nitrogen fraction—aspartic acid, glutamic acid, serine, asparagine, glutamine, alanine, valine, leucine and gamma amino butyric acid—were the same under long- and short-day conditions. However, the relative proportions of the amino acids were drastically changed. For example, glutamine was very prominent in the leaves of the long-day plants. The relative amounts of the individual amino acids varied considerably in the leaves, roots, and stems.

Studies were also carried out on *M. piperita* to determine the influence of mineral deficiencies on the soluble nitrogen constituents. The plants were grown under glass, on long- or short-days and at a high night temperature. It was found that the mineral deficiencies brought about profound changes in the total soluble nitrogen fraction and in the relative proportions of the individual amino acids in the soluble nitrogen fraction. Imposed upon these differences was the effect of the long- and short-days. Nitrogen and phosphorus deficiencies brought about a reduction in the total amount of soluble nitrogen in the leaves while deficiencies of potassium, calcium, and sulfur resulted in an increase in the soluble nitrogen fraction as compared to the full nutrient solution. A feature of sulfur deficiency under long-days was the fact that arginine was the major constituent of the soluble nitrogen fraction. This was not true under short-day conditions.

Steinberg (1956) carried out a collaborative study with Steward and Zacharius on the effect of micronutrient deficiency on the free amino acids of tobacco. The results are shown in Table 2. As can be seen the micronutrient deficiencies altered drastically the distribution of the free amino acids of the soluble nitrogen fraction. The amount of soluble nitrogen was

TABLE 2.—FREE AMINO ACIDS IN FRESH LEAVES OF DEFICIENT CONNECTICUT BROADLEAF TOBACCO AT THE TIME OF FLOWERING OF THE CONTROLS
(from Steinberg, 1956)

	%N of total free amino nitrogen in deficient leaves of tobacco						
Amino Acid	Control	Mo	Fe	B	Cu	Zn	Mn
Amino butyric acid	18.6	8.1	3.5	7.6	5.5	3.4	9.0
Alanine	18.2	2.6	2.1	3.3	2.7	1.8	4.0
B-alanine			tr.				
Arginine	tr.	2.0	6.9	3.1	8.1	9.7	9.6
Asparagine	tr.	none	39.2	9.1	55.8	10.9	40.7
Aspartic acid	tr.	1.0	1.9	1.0	1.7	2.4	2.8
Glutamic acid	11.0	1.0	1.8	2.3	2.7	5.1	7.0
Glutamine	12.3	12.7	21.6	8.8	4.0	35.1	10.1
Glycine	8.2	4.1				5.8	1.5
Leucines	2.7	1.5	1.0	1.7	0.8	1.9	1.1
Lysine	tr.	56.4	3.3	4.0	4.0	2.0	0.9
Methionine sulfoxide					0.2		
Phenylalanine		3.9		4.0	2.3	1.8	
Proline	13.1	2.2	1.4	11.5	3.4	8.5	3.4
Serine	8.2	2.0	2.2	1.4	2.6	3.6	1.4
Threonine	5.4	1.0	0.9	1.8	1.4	4.0	1.6
Tyramine			10.6	38.7	3.1	1.3	6.9
Tyrosine		0.9	2.0	1.1	1.3	1.2	
Valine	2.2	0.8	1.6	0.8	0.5	0.9	0.4
Total	99.9	100.1	100.1	100.0	100.0	99.4	100.2
Micrograms N/gram	13.0	208.3	1695.2	879.7	1925.0	1072.5	366.6

increased over the control plants. It should also be mentioned that tobacco leaves contain several amino acids not found in *M. piperita*—proline, threonine and glycine.

Using new analytical techniques for determining the individual components of the soluble nitrogen fraction, Boynton, Yatsue, and Kwong (1961) studied the influence of a number of environmental and nutritional factors on the intermediary nitrogenous compounds in the leaves of the strawberry plant. Such factors as potassium and magnesium deficiency, winter chilling, day length, night temperature, and gibberellic acid were studied. Table 3 summarizes some of the information they gathered. In this table a + sign means that the nitrogen compound increased under the influence of the nutritional or environmental variable while a – sign means that the nitrogen compound decreased. It can be seen, for example, that a potassium deficiency resulted in an increase in the sum of soluble nitrogenous constituents in both young and old leaves. However, with respect to the individual nitrogenous compounds, asparagine, glutamine, gamma aminobutyric acid, and arginine increased under a potassium deficiency while glutamic acid decreased.

The results of the experimental work mentioned above clearly show that nutritional and environmental factors play a major role in modifying the total amount of soluble nitrogen in plant tissue as well as the relative

TABLE 3.—THE DIRECTION OF THE EFFECTS OF CERTAIN NUTRITIONAL AND ENVIRONMENTAL VARIABLES ON SOME OF THE INTERMEDIARY NITROGENOUS CONSTITUENTS IN STRAWBERRY LEAVES
(from Boynton, Yatsu and Kwong, 1961)

	–K (vs complete)	–Mg (vs complete)	Winter chilling (vs none)	Short days (vs long)	Cool nights (vs warm)	Gibberellic acid (vs. none)
Sum of N compounds						
Young leaves	+	+	+	+	+	+
Older leaves	+	+				
Aspartic acid						
Young leaves			+	–	–	
Older leaves						
Glutamic acid						
Young leaves	–	–	+	–	–	–
Older leaves	–	–				
Asparagine						
Young leaves	+		–	–	–	–
Older leaves	+					
Glutamine						
Young leaves	+		+	+	+	–
Older leaves		+				
Gamma Amino Butyric acid						
Young leaves	+	+	+		+	
Older leaves	+	+				
Arginine						
Young leaves	+	+	+	+		–
Older leaves	+	+				
Pipecolic Acid						
Young leaves		+	–	+	+	
Older leaves		+				

amounts of individual nitrogenous compounds. Such experimental parameters as nutrition, photoperiod and thermoperiodicity all influence the nitrogen transformation and utilization of plants. Future research must determine the relationships between these experimental variables and the metabolism of plants.

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Gaseous Loss and Mobility as Factors in Nitrogen Efficiency[1]

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The ultimate destiny of nitrogen applied to the soil may be divided into four categories. They are uptake and removal of nitrogen with harvested crops; leaching loss to ground waters; gaseous loss to the atmosphere; and extended retention in the soil, primarily in the plant and microbiological cycles. It is a relatively simple procedure to measure directly the amount of nitrogen accounted for by each of these except gaseous loss. The development of modern methods involving the use of tagged nitrogen is opening a new approach to studies of gaseous loss, but to date the estimation of its magnitude has largely been limited to an assumption that gaseous loss is the portion not accounted for by the other three measurements.

This discussion will be confined to a brief review of factors important in leaching losses; followed by a more elaborate consideration of published information and current research on gaseous losses of nitrogen, especially in the form of ammonia from sandy Florida soils. Nitrogen transformation in the soil and the implied gaseous losses in forms other than ammonia are discussed by others in contiguous papers.

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LEACHING LOSSES OF NITROGEN

Nitrate is usually the only form of nitrogen lost from soils in significant quantities. Ammoniacal nitrogen has appreciable mobility under certain conditions, such as the extremes of soil acidity or under the concentrated mass action of associated ions, but mobility seldom proceeds to the point of appreciable loss from the root zone. Even light sandy soils have the ability to absorb ammonia in the base exchange and thus retard its movement with percolating waters.

The mobility of ammonia is differentialy affected by associated ions. In leaching tests with Lakeland fine sand (4) sodium had the least effect on the mobility of ammonia. Other ions studied were found to be of the increasing order; nitrate, sulfate, magnesium, chloride, potassium and calcium when these ions were used in all combinations as neutral salts in conjunction with ammonium sulfate. The potential for calcium was about double that for nitrate and about 20 times that for sodium. Thus it could be expected that nitrate of soda would have a very low potential for the movement of ammonia as compared to a material with appreciable percentages of soluble calcium and chloride ions.

The effect of strong soil acidity on mobility of ammonia, exclusive of its indirect effect through nitrification is of importance only in soils maintained at moderate to strong acidity in the range below about pH 5.5. This is primarily because of lack of other bases to be replaced and move in its stead (3). In general from three to five times as much ammonia was leached in tests with several Florida soils at pH 4.0 as at pH 5.5. The effect of pH on nitrification of ammonia and therefore on the reduction of potential for leaching of ammonia as such is very marked. Ammonia will persist for extended periods in strongly acid soils and thereby increase the time available for its movement (3). But, regardless of soil pH, the overall potential for leaching of nitrogen is much less where ammonia is involved rather than nitrate nitrogen.

A temporarily mobile form of nitrogen not naturally occurring in significant quantities in the soil but widely used as fertilizer is urea. While there is some absorptive capacity for urea by soils, generally it may be assumed that when urea is first applied it is free to move with the soil water. This period of mobility usually is very short—from a few hours to about three days in soils having active microbiological populations to produce urease, the enzyme that hydrolyzes urea to ammonium carbonate. The rate of conversion will be slowed, and the period of mobility as urea proportionately lengthened by the presence of heavy metal inhibitors of urease, such as copper residues; or by the limited microbiological activity existing in certain subsoils, strongly acid soils and virgin soils (5). But even under these conditions the extension of the period of mobility is only a few days at most and can be disregarded in predicting leaching losses of nitrogen unless heavy rains follow immediately after fertilization The relative mobilities of nitrate, urea, and ammonia are illustrated by data from a lysimeter experiment (5). The lysimeters were four feet deep, 22 square feet in area and filled by profile with Lakeland fine sand. They were treated with urea, ammonium nitrate or ammonium sulfate to give 60 pounds of nitrogen as urea, ammonia or nitrate per acre. Leaching was started immediately after treatment using small increments of water until five inches of water had passed through the lysimeters in 24 hours.

No measurable ammonia was leached, as could be predicted from a long

history of operation of these lysimeters. Urea, leached as such, amounted to 14.7 percent of that applied, while 33.9 percent of the nitrate was leached. Appreciable urea hydrolysis could have taken place during leaching, but the period was too short for significant nitrification. For practical purposes nitrate is assumed to be completely mobile with the soil water, therefore the 33.9 percent indicated that sufficient water was applied to remove about one-third of potentially mobile constituents. Two things are readily apparent. Urea is significantly mobile shortly after application to light soils, especially as compared to ammoniacal nitrogen, and the amount of precipitation necessary to approach complete removal of soluble constituents is considerable even for a sandy soil.[3]

Data on removal of chlorides under normal slow leaching from these lysimeters indicated that about ten inches of water would have to pass the profile, although this estimate should be reduced somewhat because of low moisture tension in the bottom of the lysimeter resulting from interrupting the soil profile (6).

Data from these lysimeters also have shown that the ability of a well developed root system to reduce nitrate loss by plant uptake is truly remarkable—so much so that the leaching loss of nitrates under any but heavy or extended precipitation can be ignored except during periods of dormancy or early growth before an efficient root system is developed (6). Current data on field tests reported in a section to follow support this contention.

GASEOUS LOSSES OF NITROGEN

That gaseous loss of nitrogen as ammonia takes place from calcareous soils in the alkaline range, or in the form of elemental N_2 or various oxides under anaerobic conditions is well known, but the degree to which nitrogen may be lost as ammonia from acid soils, or as other gaseous forms of nitrogen from soils essentially well aerated has not been appreciated until recently.

Work in Florida has brought to attention the fact that gaseous losses of ammoniacal nitrogen following surface application to sods or bare acid sandy soils may reach significant amounts. That this loss might be appreciable was first recognized by the writer in 1950 when the lysimeter work involving urea was initiated (6) but specific measurement of gaseous loss was not begun until 1958. Work by Burton and DeVane (1) suggested that top dressed urea nitrogen was inferior to certain other sources. In addition there have been numerous reports in which response to urea nitrogen was highly erratic. A 1959 report by Volk, Kelly and Blue (8) on comparative responses of oats and millet to various nitrogen sources showed the same general trend. Overall net recovery of nitrogen from urea in a series of 25 and 50 pound nitrogen top-dressing treatments was only 53.9 percent as compared to 72.8 percent for ammonium nitrate.

Work on volatile loss of ammonia from soils has been summarized recently by Meyer, *et al.* (2) and except for a review of Florida work will not be repeated. The first work in Florida specifically indicating significant gaseous loss from surface applied urea was reported in January of 1959 (7).

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[3]Depth of profile is not a factor except in time of appearance of soluble constituents in leachates as long as it exceeds rooting depth or the height of significant return of moisture by surface evaporation.

These data were obtained by the direct measurement of gaseous ammonia, using an especially developed procedure. The ammonia was trapped by a static absorber consisting of an acid soaked glass wool pad in the bottom of a glass dish inverted over a treated area. Gaseous loss of ammonia from urea applied to turf on acid sandy soils ranged from 20 to 30 percent during the first week as compared to less than one percent from ammonium nitrate. A subsequent report (9) showed that this type of loss also took place from surface application to bare acid sandy soils. The loss from the latter was about 30 percent, more or less depending on soil texture and pH, with some instances of losses up to one-half of a 100 pound per acre nitrogen application.

That these losses from bare soil applications would be reflected in crop response was shown by greenhouse cropping of field treated soils (10). Reduced nitrogen recovery was as predicted by the direct measurement of volatile ammonia (9).

CURRENT RESEARCH ON GASEOUS LOSS OF AMMONIA AND GRASS RESPONSES TO VARIOUS NITROGEN SOURCES

The apparent effect of pH of acid soils, and historical knowledge of ammonia loss from calcareous soils led to a conclusion that lime top-dressed on acid soils could be a markedly enhancing factor not only for urea, but possibly for ammoniates such as ammonium sulfate and ammonium nitrate as well.

Areas of established Pensacola Bahiagrass and Coastal Bermudagrass sods were selected for the tests. The soil, Leon fine sand, had had lime previously incorporated for prior work so that the soil pH was 5.6—5.7. Eight blocks, subdivided into surfaced-limed and no-lime treatments were laid out on each area, and one ton of standard calcic agricultural lime per acre applied to the surface of the limed sub-blocks. Four months later tests were made to determine, by direct trapping of ammonia gas, the effect of this surface lime on the volatile loss from a 100-pound per acre nitrogen application of urea, ammonium sulfate or ammonium nitrate. Data appear in Table 1.

It is obvious that the surface lime enhanced the ammonia loss from urea since the volatile loss as ammonia increased from 29 percent to 36 percent. Losses from the ammonium sulfate and ammonium nitrate were negligible from the unlimed soil as expected, but the loss from ammonium sulfate on limed soil was appreciable as 19.7 percent of the application. Apparently the lesser amount of ammonium in ammonium nitrate and the greater activity of the nitrate ion as compared to the sulfate in the presence of high calcium kept the loss from ammonium nitrate at a relatively low level. This suggests that ammonium nitrate would be the favored material on recently surface-limed turfs.

Approximately 22 weeks after top liming, all of the plots were further subdivided and differentially treated with nitrogen as shown in Table 2. Four 50 pound nitrogen applications were distributed over two seasons. Data for the first season are complete and reported in Table 2 as yield and percentage nitrogen recovery. Those of the second season are only partially complete but presented in Table 3 to show the trend, as the effect of the surface liming is modified by acidification from treatments, as well as shallow incorporation by harvesting activities and other disturbances.

TABLE 1.—VOLATILE LOSS OF NH_3 FOLLOWING SURFACE APPLICATION OF LIME AND NITROGEN TO PENSACOLA BAHIAGRASS SOD ON LEON FINE SAND OF pH 5.8.

Nitrogen Treatment 100 lb. N from	Field Location	Nitrogen Loss as NH_3 in 2 Weeks: No Top Lime	Nitrogen Loss as NH_3 in 2 Weeks: 1 Ton Calcic Lime on Surface 4 months Previous
Ammonium sulfate	1	0.5%	14.8%
	2	0.7	20.9
	3	0.1	22.6
	4	----	20.5
	Ave.	0.4	19.7
Urea	1	28.0	35.0
	2	29.9	37.7
	3	29.1	30.4
	4	-----	41.0
	Ave.	29.0	36.0
Ammonium nitrate	1	0.3	3.5
	2	0.2	4.1
	3	0.3	3.1
	4	---	2.8
	Ave.	0.3	3.4

It is readily apparent that the response to nitrogen from urea is lowest, as would be expected from prior data. The most striking differences are those due to surface liming. In every instance during the first season the response to nitrogen with surface timing was less than to nitrogen on the unlimed areas where urea or an ammoniate was used. That this was not due to more rapid nitrification and increased leaching is shown by the response to calcium nitrate, a material included in the test specifically to evaluate this factor and to isolate the response to lime as such, if any.

Possible differences among materials in general, not associated with the effect of lime, are not sufficiently obvious to be discussed at present but must await completion of all data and statistical analysis for precise evaluation.

Data in Table 3, consisting of dry weight yields only for the first two harvests of the second season show the same trend in effect of top-dressed lime for the first cutting. However, it appears that the differentiating effect of surface liming is disappearing and may actually reverse as the possible effect on ammonia loss becomes dominated by the crop response to favorable pH or calcium supply, and to increased leaching potential of nitrates.

To what extent liming or soil pH plays a part in differential gaseous loss in forms other than ammonia in these tests is a matter for speculation and further study. The relative inconsistency of low gaseous ammonia loss from ammonium nitrate by direct measurement as compared to an appreciable reduction in recovery in forage with liming indicate that enhanced affect of liming on gaseous loss in forms other than ammonia should be investigated.

There is relatively widespread use of materials such as A-N-L, Cal Nitro and Calcium Ammonium Nitrate in which 33.5 percent ammonium nitrate is reduced to 20.5 percent by the addition of calcic or dolomitic lime for granulation and ease of spreading. The possibility exists, in the light

TABLE 2.—YIELDS AND NITROGEN RECOVERY FROM SURFACE-APPLIED NITROGEN WITH AND WITHOUT PRIOR LIME TOP-DRESSING. FIRST SEASON (1960) LEON FINE SAND pH 5.7*

Treatment 50 lb. N Applications 4/4/60 and 6/17/60	Harvest Dates 1960	Net Pounds 70°C Dry Weight Yields				Net Pounds Recovery of Applied Nitrogen (Total Net pounds is also % recovery of 100 lb. N)			
		Pensacola Bahiagrass		Coastal Bermudagrass		Pensacola Bahiagrass		Coastal Bermudagrass	
		Surface Limed	Not Limed	Surface Limed	Not Limed	Surface Limed	Not Limed	Surface Limed	Not Limed
Ammonium Nitrate	5/27	364	335	1191	1178	6.6	7.6	17.1	17.7
	7/20	1578	1844	2168	2224	19.4	21.8	23.8	28.1
	10/3	1107	1606	428	688	10.7	15.6	2.6	5.4
	Total	3049	3785	3787	4090	36.7	45.0	43.5	51.2
Ammonium Sulfate	5/27	295	270	837	1231	5.3	6.0	11.2	17.0
	7/20	1342	1927	2075	2048	16.6	21.8	25.2	25.3
	10/3	1080	1628	565	711	10.2	16.3	4.0	6.0
	Total	2717	3825	3477	3990	32.1	44.1	40.4	48.3
Urea	5/27	162	234	634	893	3.3	4.2	9.6	13.5
	7/20	1203	2121	1653	1738	14.4	18.8	19.0	24.9
	10/3	975	1631	561	786	9.2	16.1	3.6	7.3
	Total	2340	3986	2848	3417	26.9	39.1	32.2	45.7
Calcium** Nitrate	5/27	319	149	1415	1108	6.8	4.5	22.1	18.4
	7/20	1614	1749	1767	1604	19.9	20.5	20.4	21.4
	10/3	1199	1434	345	383	12.6	13.1	2.1	3.6
	Total	3132	3332	3527	3095	39.3	38.1	44.6	43.4

*Extended dry period reduced the first harvest. Vasey grass contaminated the Bermuda area, especially in 1961. One ton calcic lime top-dressed 10/28/59 on limed plots.

**5 $Ca(NO_3)_2 \cdot NH_4NO_3 \cdot XH_2O$

TABLE 3.—GRASS YIELDS FROM FOUR NITROGEN SOURCES WITH AND WITHOUT PRIOR SURFACE LIMING.
Second Season, 1961. Leon fine sand pH 5.7

Treatment 50 lbs. N. Applications on 4/12 and 6/14	Harvest Dates 1961	Pounds 70°C Dry Weight Yield per Acre* — Pensacola Bahiagrass: Surface Limed 1 T. 10/28/59	Pensacola Bahiagrass: No Lime	Coastal Bermudagrass: Surface Limed 1 T. 10/28/59	Coastal Bermudagrass: No Lime
Ammonium Nitrate	6/2/61	950	1140	1190	1430
	8/21/61	2240	2270	4010	3930
	Total	3190	3410	5190	5360
Ammonium Sulfate	6/2/61	1000	1210	1320	1640
	8/21/61	2400	2520	4090	3680
	Total	3200	3720	5410	5320
Urea	6/2/61	750	1090	750	1430
	8/21/61	2110	2760	2920	3640
	Total	2850	3850	3680	5070
Calcium Nitrate	6/2/61	1000	1110	1300	1220
	8/21/61	2300	2540	3880	3320
	Total	3300	3650	5170	4540

*1961 data on third (residual) harvest and nitrogen analyses of grass not completed to date. Average of 8 replicates.

of data just reported, that lime in the granules would enhance ammonia loss if these materials were top dressed. Table 4 presents data that indicate such a loss would be of minor importance as compared to losses from urea; and that calcic and dolomitic lime do not have any differential effect when used in the process.

SUMMARY

The leaching loss of nitrogen takes place primarily in the form of nitrate. Except for periods of continuous or heavy rainfall, extensive loss takes place only from fallow soils, or during crop dormancy, or with new crops before an extensive and efficient root system is developed. Mobility and loss by leaching of urea or ammoniacal nitrogen may be significant in

TABLE 4.—COMPARISON OF GASEOUS LOSS OF AMMONIA FROM UREA AND FROM LIME-CONDITIONED AMMONIUM NITRATE, SURFACE-APPLIED TO BARE SOIL.
LAKELAND FINE SAND pH 5.6

100 Pounds Nitrogen From	Nitrogen Loss as Ammonia in 10 Days*
Urea 45% N (Prilled)	48.6% ± 0.8
Ammonium Nitrate Plus Calcic Lime 20.5% N (pelleted)	3.9% ∓ 0.2
Ammonium Nitrate Plus Dolomitic Lime 20.5% N (pelleted)	3.7% ± 0.2

*4 replicates

some instances, but, in general, loss of nitrogen in these forms may be disregarded in predicting nitrogen efficiency.

Apparently gaseous loss of nitrogen is significant, and to the extent that this loss represents ammonia it is possible to improve nitrogen efficiency by selection of materials and adjustment of cultural practices. Nitrogen top dressed on tilled crops should be covered. Ammonium nitrate is preferable to either urea or ammonium sulfate for application to turf immediately following top dressed lime. Urea is the least preferable even on non-limed turf unless wetted in, as would be possible for ornamental turfs. Sources carrying only nitrate will deserve close study as top dressing for turf when and if they become competitive in cost per pound of nitrogen.

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Nitrogen for Vegetable Crops

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Certain vegetable crops have always been considered to be heavy feeders, meaning that relatively large amounts of plant food are utilized per short period of growing time. The following discussion will consider quality and quantity of nitrogenous fertilizers required to obtain an optimum in quality and quantity of vegetable product with special consideration of the time variable.

Quality of nitrogen: The nitrogen in the soil exists in either organic or inorganic form. In most normal cultivated soils the breakdown of organic matter and additions of ammonium salts tends toward a low nitrate/ammonium ratio; but because of conversion to a nitrate end product, a high nitrate/ammonium ratio is found in the more normal root zone. From a standpoint of plant utilization this tends to identify all nitrogen source materials as potentially ammonium or nitrate, either of which can be absorbed and assimilated by plants.

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Organics in fertilizers furnish a nitrogen source that does not leach nor become available to plants until broken down. Such material may also furnish other plant nutrients, especially certain minor elements, that may not otherwise be supplied to the plant. However, most research has indicated that the cheaper inorganic nitrogen sources, if utilized properly, are at least equivalent to the organic sources. As an exception, recent experiments in Immokalee (2) have indicated that markedly better yields of watermelons were associated with fertilizer containing 30% of the total nitrogen from a water insoluble organic source. Also, compared to the above, decreasing yields were associated with ammonium sulfate, ammonium nitrate and sodium nitrate in that order. At present the reason for the above mentioned effect has not been satisfactorily explained.

Results of nitrogen source experiments conducted at the Gulf Coast Experiment Station (3) indicate the pH of the soil can alter the response of certain vegetable crops to different nitrate and ammonium salts. As pH's increase above 6.0, lower yields and poorer quality sweet corn, cucumbers and pole beans were associated with the all nitrate source materials compared to the ammonium. As pH's decrease below 5.5 poorer tomato and potato yields were associated with the all ammonium source materials. A physiological disorder known as "nutritional leaf roll" of potatoes and tomatoes is a result of the preceding combination (4, 8). A low calcium-ammonium ratio is also favorable for development of such physiological disorders as blackheart of celery and blossom-end rot of tomatoes and peppers (4).

On the old sandy soils at Sanford (10) celery yields have been increased when nitrate was compared to ammonium as a source of nitrogen. Additions of nitrogen and especially nitrate nitrogen during cold weather to the organic soils of the Everglades and Zellwood areas have been associated with increased yields of celery, spinach, lettuce and other vegetable crops (1, 11).

Certain research contributions which may explain in part some of the above mentioned responses are as follows: Tiedjens and Robbins (7) growing tomatoes, soybeans and peach seedlings in sand cultures concluded that ammonium was most efficiently assimilated at pH 7.0 or above, whereas nitrates were most efficiently assimilated at a pH between 4.0 and 5.0. Ammonium although absorbed at pH 4.0, was not assimilated. It should also be pointed out that the nitrate-source materials tend to raise the pH, whereas ammonium lowers it. Certain minor elements such as boron, manganese, zinc, copper, and iron become less available and molybdenum more available as pH's increase. Ammonium when absorbed by the plant becomes a competitor to other cation uptake, especially calcium, (4, 9). When the nitrogen is absorbed as an anion (nitrate) that factor is eliminated, but increased nitrate uptake causes increased organic acid production by the plant which in turn increases calcium requirements (5).

Except for special situations discussed above, the source of nitrogen utilized for vegetable crops generally should be determined by cost per unit of nitrogen supplied to the crop. Normally the cheapest is as good as, and often better than, the most expensive.

Quantity of Nitrogen: The quantity of nitrogen used for vegetable crops in Florida may vary from 0 to 500 or more pounds per acre. Except for legumes it is obvious that when nitrogen is not added, the cover crop or other soil organic matter is expected to supply the nitrogen requirements

of the crop. For most Florida vegetable crops, a relatively large portion of the nitrogen supply is dependent on the rate of breakdown of the organics. Thus yield and quality of the crop as they are related to nitrogen requirements depend on that process. When one is trying to obtain optimum yield and quality the availability of sufficient nutrients to the plant per short period of time is especially important. This will be brought out in the discussion that follows. In any event, to obtain the optimum, the requirement for nitrogen cannot be dependent on the breakdown of organics.

Celery has been long noted as a gross feeder; as much as 2 to 5 tons of fertilizer including 200 to 500 pounds of nitrogen is supplied to a crop even when grown on an organic type soil. A good yield of 1000 crates per acre represents the removal of approximately 6000 lbs. of dry plant material which on the average would contain 200 to 250 pounds of nitrogen.

Although not considered a vegetable, the extensive research and resultant high yields with field corn can be cited as an example of the associated nitrogen requirement. One hundred bushels of corn representing 8,000 to 10,000 pounds of dry material (grain and stover) would contain about 160 to 200 pounds of nitrogen. Mr. J. H. Roadruck of Brookston, Indiana in 1960 produced 231 bushels per acre of corn on a 16-acre test block when 428 pounds of nitrogen was applied. However, for the record, a yield of over 300 bushels per acre was recently set in Mississippi. As indicated in Table 1 the yield of sweet corn has not paralleled that of field corn. In fact only a few vegetable crops have exceeded the general state average which is indicated in Table 1 by the dry matter yield (1,000 to 2,000 lbs

TABLE 1.—YIELDS, NITROGEN CONTENT AND RATES OF NITROGEN UTILIZATION OF VEGETABLE CROPS

Crop	Yield per acre**			Nitrogen content**		Average nitrogen, acre/wk. (lbs.)
	Fresh basis	Dry weight (lbs.)		% of dry tissue	Weight (lbs.)	
		Plant	Fruit			
Beans	150 bu.	500	500	3.5	35	3.5
Cucumbers	200 bu.	500	1000	3.5	53	4.5
Squash	150 bu.	400	600	3.5	35	4.5
Watermelon	150 cwt.	1000	1000	3.5	70	4.5
Potatoes	180 cwt.	1500	2700	3.5	147	9.2
Peppers	500 bu.	750	1250	3.5	70	4.5
Celery (A)	800 cr.	4800	......	3.5	168	11.0
(B)*	1500 cr.	9000	......	3.5	315	20.0
Sweet Corn	200 cr.	1400	2100	3.0	105	8.8
Field Corn*	200 bu.	6000	10000	2.0	320	20.0
Tomatoes (A)	200 bu.	1000	1000	3.5	70	4.5
(B) wide row*	500 bu.	1500	2500	3.5	140	10.0
(C) staked*	500 bu.	2500	2500	3.5	175	9.7
(D) trellised*	500 bu.	7500	7500	3.5	525	22.0

*Except for the field corn and additional celery (B) and tomato (B, C, D) data, yields presented were taken from 1959-60 crop data published by the Florida Crop and Livestock Reporting Service, Orlando, Fla. Yields selected were an average of the highest reported. The B, C, D data are averages of the present maximum being produced.

**Dry matter yields and nitrogen figures are averages calculated from data obtained at the Gulf Coast and other experiment stations. The quantity of nitrogen supplied in fertilizers may be 50% more than the figures given because these do not include root content, inefficient utilization or loss due to leaching.

acre) and the associated nitrogen requirement (50 to 100 lbs. per acre). A yield of 5,000 to 10,000 pounds of dry matter per acre or utilization of 200 to 400 pounds of nitrogen in a 3- to 4-month growing period might be considered a practical maximum at the present time. For this maximum approximately 20 pounds of nitrogen per acre per week could be used as a guide for any average rate of application. However, the average is not a practical basis for supplying nutrients, especially in Florida where leaching rains may occur at any time. Also plant utilization is highest when greatest growth occurs or as a crop approaches harvest. For maximum yield of vegetable crops, up to 50 pounds or more of nitrogen per acre per week is required during periods of maximum utilization.

Let us consider two types of tomato culture which best illustrate the nitrogen-time factor of intensive production:

(1) Wide row type-approximately 1,200 large unpruned, semi-staked plants are grown per acre on high beds with ditches between each row. The harvest period may extend from 3 to 4 weeks with a peak production about 250 or more bushels per week. That amount of fruit alone requires about 40 pounds of nitrogen not considering the simultaneous root and plant requirement. At present, a 500 bushel per acre yield means 25 pounds of fruit per plant. However, it has been observed that as many as 240 fruit have been set on a single plant; thus the potential if all became marketable size (one third pound per fruit) potentially 80 pounds could be harvested from a single plant. The point to be emphasized is the tremendous quantity of fruit developing in a relatively short period of time. The nitrogen and entire nutrient supply available would have to be geared accordingly.

(2) Trellised type—approximately 7,000 to 10,000 pruned, trellised plants are grown per acre. Harvesting extends over a 12 to 16 week period and yields average 100 bushel per acre per week with 10 pounds total per plant considered good. In contrast to the "wide row" type the nutrient requirement is not concentrated during a short period, but the eventual total quantity is much larger as is indicated in Table 1.

SUMMARY

Optimum yields and quality of vegetables can be obtained by using the cheaper inorganic nitrogen sources and are generally recommended for the average to best soil environment. The exceptions and associated abnormalities are pointed out. Best quality is generally associated with best yields and reflects the approach toward an optimum nutrition. It is considered that emphasis should be pointed toward use of greatly increased quantities of nitrogen with respect to rate of utilization in order to reach a practical maximum. At present this maximum is represented by production of 5,000 to 10,000 pounds of dry plant material utilizing 200 to 400 pounds of nitrogen during a 3 to 4 month period.

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Nitrogen Transformations in Citrus Trees[1]

IVAN STEWART[2]

Most of the nitrogen studies made on citrus have been concerned with the influence of sources and rates of this element on yields, fruit quality, and tree and root growth. There have been few reports on the nature of the changes that nitrogen undergoes after it enters the tree. It is the purpose of this paper to discuss some preliminary studies made on nitrogen compounds occurring commonly in citrus trees.

Citrus trees differ from many plants in that they seldom contain nitrate nitrogen. The writer has never detected it in the roots, leaves or bark of trees growing in the field; but it was usually prevalent in grass and weeds growing under the trees. However, Chapman (2) found almost 4,000 ppm in roots and about 1,300 ppm in leaves of seedlings growing in a high nitrate nutrient solution. Another form of nitrogen commonly applied is ammonia but citrus is not very tolerant to this form. In Florida soils, nitrogen in the ammoniacal form is readily converted to nitrate and this is believed to be the primary form of nitrogen taken up by citrus. If nitrate is taken into the roots and none is found inside, then it must be concluded that the nitrate is reduced either at the root surface or shortly after entering the plant and converted into organic forms of nitrogen. This also suggests that citrus roots have an efficient nitrate reductase system. Methods now commonly used for measuring this system have not been effective in measuring the nitrate reductase activity of citrus roots. However, it must be concluded that some such system does exist.

In citrus, nitrogen occurs mainly as amino acids and as the amides glutamine and asparagine. In this paper the amides will be treated as amino acids. The amino acids occur primarily in proteins and also as free amino acids. It is the latter ones that will be discussed here.

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Materials and Methods.—Leaf samples for amino acid analysis were taken from citrus trees growing in the field, put into polyethylene bags, and frozen in dry ice. Root samples were washed in the field and then frozen. Seedlings growing in the greenhouse were put into hot ethanol and stored in a deepfreeze. All samples were extracted four times in 80% ethanol with a Lourdes mixer at a speed of 16,000 rpm. The extract was passed through two columns of Dowex 50 ion exchange resin to separate the amino acids from sugars, organic acids, inorganic ions and other interfering substances. The first column was in the NH_4^+ form which removed the basic amino acids—arginine, lysine, and histidine. The other amino acids were collected on the second column which was in the H^+ form. The acids were then eluted from the columns with NH_4OH and chromatographed on No. 52 filter paper 18 x 22 inches. The basic acids were run by one dimension on EDTA buffered paper using a procedure developed in this laboratory. All other acids were run by a two dimension method of Levy and Chung (4). Following separation of the acids on paper the chromatograms were dipped in ninhydrin and the amino acids were determined by reading the maximum density of the spots with a Photovolt densitometer Model 525 and compared with known standards.

Radioautographs were made of chromatograms containing radioactive amino acids by exposing them to no-screen X-ray film prior to dipping in ninhydrin. Using the film as a guide to the location of the spots, counts were made on the chromatograms using a thin window Geiger tube connected to a Nuclear Chicago rate meter.

Results—Free Amino Acids in Citrus—Over one-fourth of the total nitrogen in citrus leaves may occur in the form of free amino acids. The amount present at any time depends on many factors some of which are the age of growth, variety, nutrition, and undoubtedly many others that are not now recognized. The amino acids that are commonly found in the leaves are aspartic acid, glutamic acid, serine, glycine, threonine, alanine, gamma amino butyric acid, proline, arginine, lysine, asparagine and glutamine. A typical chromatogram is shown in Figure 1. Citrus leaves may also contain small amounts of tryptophane, leucines, phenylalanine, valine, tyrosine, histidine, ornithine and several unknown compounds that are sensitive to ninhydrin which are probably amino acids or amines. Two of these unknown compounds separate in the vicinity where cystine and cysteine is expected. However, neither of these amino acids has been identified.

Proline and asparagine generally occur in the largest amounts of any of the amino acids in citrus. Asparagine is usually high in young leaves and as the growth matures may decrease to amounts that are not readily detectable. Proline on the other hand may remain high throughout the age of the leaf. This amino acid occurs as high as 2.5% of the dry weight of the leaves but usually it is about 0.5%

Variety—A comparison was made of the amino acids in the new and old leaves of 13 varieties of citrus. The samples were taken when the new flush of growth was coming out in the spring. Pomelo contained the highest amounts of free acids while the Temple orange contained the least (Table 1).

An unknown compound with basic properties was chromatographed with lysine and arginine with an Rf value of .65 in cresol-phenol. It gives a reddish-brown color with ninhydrin and was found in considerable quantity in the leaves of oranges, tangerines, Temples, and tangelos. However,

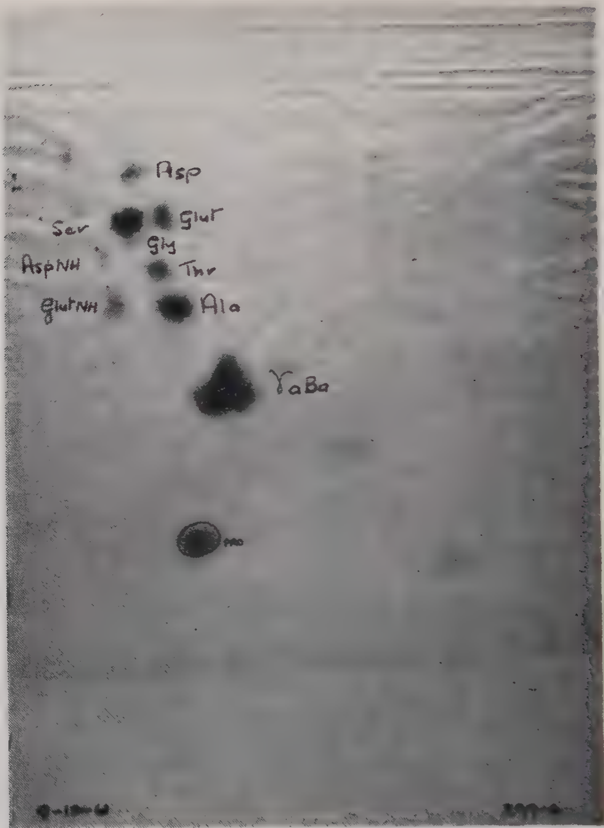


Fig. 1.—A Typical Two Dimensional Chromatogram of the Amino Acids in Citrus Leaves.

it has not been found in the roots of any variety or in the leaves of lemon, pummelo, or grapefruit.

Age of Leaf—A comparison of the amino acids in Table 1 discloses that in most instances the young leaves contain an average of over three times as much amino nitrogen as the old leaves. The spread varied from seven times as much in the young tangerine leaves to about equal amounts in old and young lemon leaves. The two acids that varied greatly between old and new leaves were asparagine and proline. In case of the pummelo age of the leaf caused a large variation in asparagine but not in proline. While with the tangelo asparagine was about the same but the proline was about 2.8 times higher in the new leaves than in the old. For the grapefruit, Valencia, and others, both of these acids varied widely with age.

Roots vs. Leaves—In a comparison of the amino acids in roots and leaves the roots in general contained about the same or slightly more of these compounds than the old leaves but much less than the new leaves. All of the roots analyzed in this laboratory contained considerable amounts of asparagine while lysine has not been detected (Table 2).

Synthesis of Amino Acids—It has been pointed out that nitrates are

TABLE 1.—FREE AMINO ACIDS AND TOTAL NITROGEN CONTENT OF NEW AND OLD LEAVES FROM 13 VARIETIES OF CITRUS. THE ACIDS ARE EXPRESSED AS UGMS OF AMINO NITROGEN PER GRAM OF DRY WEIGHT.

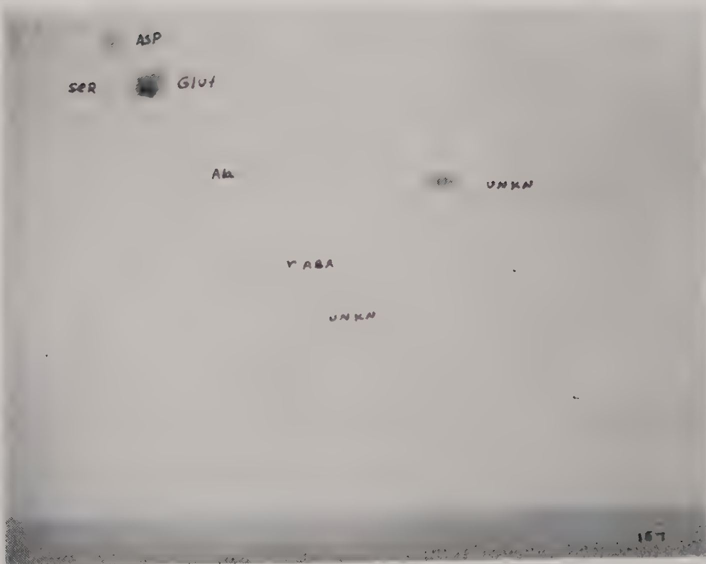
Variety	Age of Leaves	Total N per cent	Asp[4]	Glut	Ser	Glyc	Thr	Ala	γAba	Glut-NH_2	Asp-NH_2	Pro	Lys	Arg	Total Amino N
Pummelo	Old	2.58	11	14	32	13	19	56	154	162	718	889	10	154	2232
Pummelo	New	4.07	21	17	128	30	43	107	229	148	4632	856	6	122	6339
Grapefruit	Old	2.29	2	27	38	12	13	25	84	45	244	565	6	107	1168
Grapefruit	New	3.75	23	14	81	25	25	15	156	71	1604	1090	14	374	3492
Valencia	Old	2.32	7	8	32	8	12	25	117	35	117	483	8	38	890
Valencia	New	3.93	21	26	103	22	22	43	144	173	1457	1371	9	95	3486
Jaffa	Old	2.43	9	19	32	9	12	52	121	38	130	658	7	54	1141
Jaffa	New	3.99	19	16	55	21	17	42	110	149	1345	1524	12	149	3459
S. Orange[1]	Old	2.37	7	9	62	27	30	47	121	72	121	784	6	75	1361
S. Orange	New	4.05	17	15	61	24	19	64	108	118	735	661	6	269	2097
Willow S.O.[2]	Old	2.05	7	5	25	9	12	32	71	46	141	521	9	82	960
Willow S.O.	New	4.13	18	13	47	22	23	32	105	148	1061	1271	7	74	2821
Lemon	Old	2.02	9	9	50	10	15	30	100	80	82	790	17	133	1325
Lemon	New	3.52	17	15	56	19	15	47	123	51	512	704	9	101	1669
R. Lemon[3]	Old	2.67	15	40	36	15	27	44	92	64	215	331	6	64	949
R. Lemon	New	4.81	21	26	60	39	32	80	86	162	780	1300	8	120	2714
Lime	Old	2.35	18	25	42	8	17	37	148	36	36	592	10	97	1066
Lime	New	3.99	19	16	98	52	31	174	174	317	1428	1587	10	127	4033
Tangerine	Old	2.35	11	11	27	10	9	49	109	32	80	311	5	37	691
Tangerine	New	4.37	20	39	69	27	100	38	80	148	2518	1012	19	741	4811
Murcott	Old	2.59	8	9	25	8	11	30	136	30	80	610	10	193	1150
Murcott	New	4.37	19	39	70	28	25	39	122	146	462	1301	14	11	2276
Temple	Old	2.23	5	0	12	7	7	30	67	19	57	289	10	18	521
Temple	New	3.52	9	0	67	22	16	92	83	118	1271	1339	8	0	3025
Tangelo	Old	2.23	7	17	31	12	16	55	118	37	110	391	9	152	955
Tangelo	New	3.87	9	18	101	27	21	48	120	264	103	1103	13	216	2043

[1]Sour Orange
[2]Willow Leaf Sour Orange
[3]Rough Lemon
[4]Asp—Aspartic acid, Glut—Glutamic acid, Ser—Serine, Glyc—Glycine, Thr—Threonine, Ala—Alanine, γAba—Gamma Amino Butyric acid, Glut NH_2—Glutamine, Asp NH_2—Asparagine, Pro—Proline, Lys—Lysine, Arg—Arginine.

TABLE 2.—COMPARISON OF THE FREE AMINO ACIDS IN VALENCIA ORANGE LEAVES AND FEEDER ROOTS. EXPRESSED AS UGM OF AMINO NITROGEN PER GRAM OF DRY WESGHT.

	Asp	Glut	Ser	Glyc	Thr	Ala	γAba	Glut-NH_2	Asp-NH_2	Pro	Arg	Lys	Total
Leaves	5	6	20	6	13	19	98	15	....	120	7	1	313
Roots	11	23	18	11	9	14	95	24	260	260	15		729
Leaves	5	9	22	7	11	25	94	27	40	145		2	387
Roots	8	18	115	....	....	10	42	19	128	192	20		552
Leaves	10	14	33	8	11	41	144	28	51	245		3	588
Roots	10	11	14	....	8	8	66	21	220	220	59		637

Exposed 1 Hour



Exposed 20 Hours

Fig. 2.—Radioautographs of chromatograms showing radioactive amino acids from leaves of control plants exposed for two different time intervals to $C^{14}O_2$.

believed to be reduced in the roots and that nitrogen is translocated in the plants as amino acids and amides. The question arises as to whether the roots are the only place in which these acids can be formed. In order to determine if any or all amino acids can be synthesized in the leaves, rough lemon seedlings were exposed to $C^{14}O_2$ under conditions in which photosynthesis took place. In order to prevent downward movement into the roots as radioactive photosynthates, some of the plants were girdled. The girdling was done about three weeks prior to exposure to C^{14} and some symptoms of nitrogen deficiency had developed. Plants were exposed to $C^{14}O_2$ for three lengths of time—1 hour, 5 hours, and 20 hours. Radio-autographs (Figures 2 and 3) made of chromatograms on which the amino acids had been separated disclosed that amino acids are rapidly formed in the leaves from the products of photosynthesis. The nitrogen undoubtedly came from transamination. In a one-hour exposure to radioactive CO_2 aspartic and glutamic acids, serine and alanine were labeled with C^{14} in the leaves of the control plants (Table 3). None were found in the roots following an exposure of this length of time. Synthesis of amino acids appeared to be more active in the girdled plants than in the controls because in addition to the amino acids found in the control plants, those that were girdled contained radioactive gamma amino butyric acid, asparagine, glutamine, and arginine. There were no radioactive amino acids in the roots of any of the girdled plants regardless of the length of exposure to C^{14}.

Following a five-hour exposure to $C^{14}O_2$ the leaves of the control plants contained labeled gamma amino butyric acid, asparagine, glutamine, and what is believed to be ornithine, in addition to those found in the plants exposed for one hour. After five hours the amino acids in the roots were also radioactive and the same ones found in the leaves were present in the roots. The leaves of the girdled plants contained radioactive proline, in addition to the above labeled acids.

Plants exposed for 20 hours had taken up most of the C^{14} in 11 hours and after that time photosynthetic products were made mostly from non-radioactive carbon. Following this exposure some radioactive asparagine and glutamine disappeared in the control plants and radioactive proline showed up in the roots for the first time. In the girdled plants the amino acids were not translocated to the roots and much of the C^{14} in the amino acids appeared to be cycled into proline where it accumulated in large quantities (Figure 3).

Samples of the alcohol extraction residue were dried and hydrolyzed to determine if any of the amino acids in the protein were radioactive. None were found after an exposure of one hour; however, after 5- and 20-hour exposures to $C^{14}O_2$ radioactive aspartic and glutamic acid, serine, glycine, and alanine were found in the protein hydrolysate of both the control and girdled plants.

In order to compare the amino acids in girdled and non-girdled plants, determinations were made of the total amount of both radioactive and non-radioactive amino compounds. The total amount of amino nitrogen was about 11 times greater in the leaves of the girdled plants than in those of the controls (Table 4). The main differences in the individual acids were in the amounts of proline and arginine. Both were very high in the girdled plants. However, in the roots of the girdled plants no proline was found.

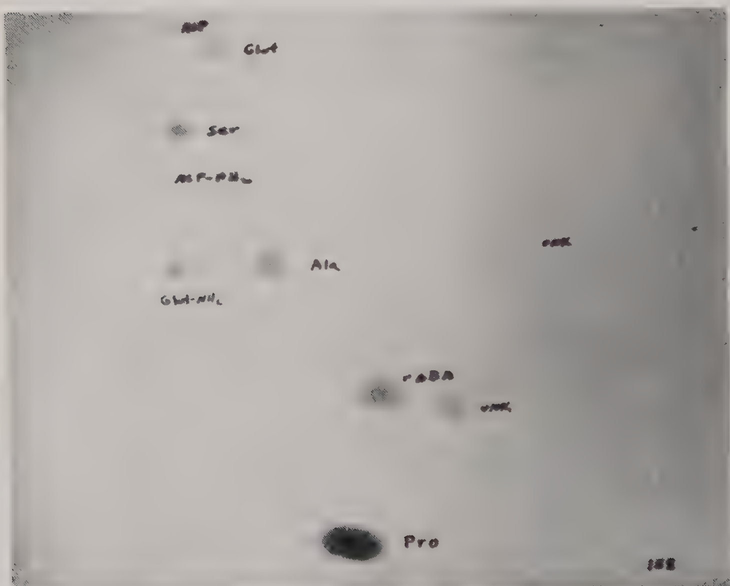
In another study to determine if the roots could synthesize amino acids from carbohydrates, seedlings were placed in a solution of C^{14} sucrose for

TABLE 3.—COMPARISON OF C^{14} IN AMINO ACIDS OF LEAVES AND ROOTS FROM GIRDLED AND CONTROL CITRUS SEEDLINGS EXPOSED TO $C^{14}O_2$ FOR 1, 5 AND 20 HOURS.

		Counts/minute/gm green weight								
	Time	Asp.	Glut.	Ser.	Ala.	γ Aba.	Prol.	Asp. NH_2	Glut. NH_2	Total
					Leaves					
Control	1	6,138	3,069	2,455	2,762				—	14,424
Control	5	7,804	14,214	4,459	5,853	9,058		975	2,090	44,453
Control	20	3,224	13,540	2,315	1,934	5,158			—	26,171
Girdled	1	2,402	3,603	8,647	1,681	1,922		2,402	1,201	21,858
Girdled	5	2,416	7,851	5,033	2,416	1,831	8,455	3,825	3,221	38,048
Girdled	20	1,506	3,263	4,518	7,279	8,032	47,690	2,008	3,514	77,810
					Roots[a]					
Control	1	--------	-------							-------
Control	5	2,326	5,039	2,713	3,876	3,188		1,938	1,357	20,737
Control	20	6,173	9,645	4,244	6,173	8,488	4,244	12,345	3,472	54,784
					Leaves Plus Roots					
Control	1	6,138	3,069	2,455	2,762					14,424
Control	5	10,130	19,252	7,172	9,729	12,546		2,913	3,447	65,189
Control	20	9,397	23,185	6,559	8,107	13,646	4,244	12,345	3,472	80,955

a. The roots of the girdled plants did not contain any detectable radioactive amino acids.

Exposed 1 Hour



Exposed 20 Hours

Fig. 3.—Radioautographs of chromatograms showing radioactive amino acids from leaves of girdled plants exposed for two different time intervals of $C^{14}O_2$.

TABLE 4.—Comparison of the Total Amino Acids in Citrus Seedling Leaves and Roots from Girdled and Control Plants.

	Ugms amino N/gm green weight												
	Asp.	Glut.	Ser.	Glyc.	Thr.	Ala.	γ Aba.	Pro.	Lys.	Arg.	NH_2 Asp.	NH_2 Glut.	Total
Leaves													
Control	7	23	2	----	----	6	9	----	8	3	----	----	58
Girdled	4	12	7	1	1	7	12	275	31	225	11	53	639
Roots													
Control	7	10	3	----	----	6	10	37	8	13	32	33	159
Girdled	5	5	2	1	----	3	5	----	15	98	33	----	167

eight hours. At the end of that time, a small amount of glutamic acid, serine, and alanine was found to be radioactive in the roots.

Discussion.—The role of free amino acids in plants is not fully understood. Generally it is believed that they are used in the synthesis of proteins but this has been very difficult to determine. In citrus amino acids undoubtedly are one of the forms in which nitrogen is translocated from the roots to the leaves of the tree. In many plants translocation of these compounds has been shown to take place through the xylem (1). In citrus the first symptoms that appear following girdling are those associated with nitrogen deficiency. This suggests that these nitrogen compounds are translocated through the phloem. Winter chlorosis which has been shown to be nitrogen deficiency (3) and associated with cold weather may be caused from poor translocation rather than a lack of nitrogen in the root zone.

These studies show that when a citrus seedling is girdled the amino acid metabolism is altered. First the girdled plant tends to accumulate the free acids, particularly proline and arginine in the leaves with a disappearance of proline in the roots. The rate of turnover of the acid pools appears to be faster in the girdled plants than in controls and eventually considerable amounts of the photosynthetic carbon is cycled into proline. It is possible that the main place of synthesis of proline is in the leaves. This is important to know since proline appears to be an important nitrogen storage constituent and could possibly be a limiting factor for growth in the case of diseases that interfere with translocation.

Summary.—Studies were made of the free amino acids in citrus leaves and roots. In a comparison of the leaves from 13 citrus varieties, 12 amino acids were commonly found and seven others were sometimes present but usually in very low amounts. Proline and asparagine were present in the largest concentration with the leaves containing up to 2.5% proline on a dry weight basis. Studies with C^{14} disclosed that free amino acids are readily formed in either the leaves or roots of citrus and the first ones formed are aspartic acid, glutamic acid, serine, and alanine. These are followed by gamma amino butyric acid, glutamine, asparagine and finally proline. The latter acid was found to accumulate in very large quantities in the leaves of girdled plants.

ACKNOWLEDGEMENT

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Nitrogen in Pasture and Field Crop Production

NATHAN GAMMON, JR. AND WILLIAM G. BLUE[1]

Of all economic plants, pastures and forage crops are probably more dependent on the carefully controlled use of nitrogen to guarantee an economic return to the farmer than any other group. Certainly a severe nitrogen shortage in any crop can bring a crop failure and economic loss, but use of some excess nitrogen on most crops has no serious effect on production. The cost of the extra fertilizer is a minor part of the relatively high overhead on crops with high cash return. This is not true for most pasture and field crops where nitrogen is necessary to grow the crop but use of excessive amounts can quickly turn the small profits into losses. This being the case, it is not surprising to find that most nitrogen fertilization work on these crops has been on the conservative side, the researchers' plans being somewhat restricted by known current economic considerations.

FIELD CROPS

Probably corn is the field crop most extensively tested for nitrogen requirement in Florida. Most of the recent tests are being reported in contiguous papers at this meeting. A previous review of the literature (16) indicates that the general corn belt recommendation of a pound and a half of nitrogen per bushel of corn (10, 11) can readily be applied to Florida conditions provided yields of not over 40 to 60 bushels per acre are sought. As yields approach 100 bushels per acre the nitrogen requirement is more nearly two pounds of nitrogen per bushel (9). The efficiency of nitrogen utilization in terms of yield response falls off rapidly beyond this point, probably because of limiting factors other than nitrogen. In general the application of part of the nitrogen as a sidedressing, usually just prior to the last cultivation, has proven to be a desirable practice since intense, though infrequent, spring rains may leach away earlier applications of nitrogen before the corn plant is large enough to utilize it (5).

Oats and other small winter grains are fertilized with 40 to 60 pounds of nitrogen per acre. If grazed and when favorable growing conditions are present some additional nitrogen may be used. But excessive nitrogen on small grains for grazing may induce nitrite poisoning of ruminants and, if grown for grain, high rates of nitrogen may cause severe lodging.

Millet can be stimulated into very vigorous growth with nitrogen levels of 60 pounds per acre but there are no recent reports on experiments with high rates of nitrogen to produce extra yield.

PASTURES

The application of nitrogen to permanent pastures has been extensively investigated in Florida. Prior to 1950, recommended rates rarely exceeded 30 pounds of nitrogen per acre per year but an increased interest in higher protein levels in grass and in greater carrying capacity for improved pastures

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in upland areas stimulated a number of studies with higher rates of nitrogen. Wallace *et al.* (15) using sodium nitrate and ammonium nitrate as nitrogen sources at rates up to 480 pounds per acre of nitrogen on clipped plots reported that the optimum response rate, source and time of application was unique to each year but that over a period of time these year to year variations cannot be anticipated and become unimportant. Under the conditions of their experiment an application of 240 pounds per acre of nitrogen per year approached optimum dry weight production most years for Pangola and Pensacola bahiagrasses. Blue and Gammon (3), using grazed plots of Pangolagrass and Pangolagrass with white clover, obtained increased yield up to rates of 240 pounds of applied nitrogen per acre the first year of their experiment. An additional increase in dry weight was noted when white clover was included. However, in the second of two succeeding years of below average rainfall, in 1954 and 1955, no significant increase in dry weight production was obtained over the lowest level of 72 pounds of nitrogen per acre. Likewise, no significant differences were noted between sodium nitrate and ammonium nitrate as nitrogen sources. This lack of response was attributed to the accumulation of nitrogen in the plants and soil over a two year period of unusually low rainfall plus some winter killing of the Pangolagrass at the higher rates of nitrogen fertilization.

In all reports on the nitrogen content of grass forage, the level in the forage has increased with the rate of fertilization. Thus if one considers the protein content, the value of the grass produced may continue to increase at levels of nitrogen higher than that which produced the optimum quantity of dry weight. Of particular interest in this regard is the work of Glover *et al.* (8), who showed that the total digestible protein in forage increases at a faster rate than the total protein. Their formula $Y = 70 \log X - 15$, where Y is the digestibility coefficient and X is the percentage of crude protein, clearly shows the increased value of high protein herbage.

Although some differences in yield were noted for different sources of nitrogen many years ago (1), the generalized recommendation has been to use the source with the lowest cost per unit of nitrogen applied to the field. The discovery of considerable gaseous loss of anhydrous ammonia at the time of application (2) and more recent reports on losses of ammonia from other nitrogen sources (13) have resulted in a need for a re-examination of nitrogen sources for pastures. It now seems that soil conditions at the time of fertilization are most important in selecting a nitrogen source. Since knowledge in this area is still incomplete, all people concerned with nitrogen fertilization of pastures should remain alert to new reports that may have practical value when applied to their particular problem.

While most of the measured gaseous nitrogen losses have been only of the ammoniacal form, there are evidently other sources of loss which in the aggregate account for the largest portion of the unrecovered nitrogen applied to pastures. In a lysimeter study by Volk (12) no more than about 60% of the applied nitrogen was accounted for in the harvested portion of the grass and in the leachate. Field plot experiments, likewise, have resulted in low percentage of recovery of applied nitrogen. The role of leaching is questionable since Volk (12) showed that under the conditions of his experiment very little nitrogen was leached under a grass sod. Prolonged experiments have eliminated the possibility of further accumulation in the roots as an unaccounted for source of this loss. Under plot techniques recovery of 50% of the applied nitrogen is about average while

under a grazing procedure, which will include some re-utilization, up to 80% may be recovered. At the same time potassium recovery is frequently 100% in plot studies and in excess of 200% considering normal re-utilization within a year under grazing (6). While it may be assumed that the recent observations on gaseous loss of ammonia can account for part of this loss, a large part of the lost nitrogen has yet to be accounted for. The possible importance of gaseous losses of nitrogen oxides as well as elemental nitrogen has been suggested (14). A major challenge remains for the soil chemist, the microbiologist and the agronomist to account for this lost nitrogen and to develop practices that will assure the cattleman that a larger portion of the nitrogen he applies on his pasture will be absorbed by the grass.

LEGUMES AS A SOURCE OF NITROGEN

Recent experiments have shown that applications of nitrogen to grass in grass-clover pastures failed to stimulate additional grass growth (7). This is not surprising when one considers the general improvement in growth of pasture legumes through natural selection, introduction of new varieties, and better fertilization in recent years. Plot experiments by Blue and Winsor (4) have shown an annual recovery of nitrogen in the clippings of ungrazed white clover-Pensacola bahiagrass plots of 300 pounds per acre of nitrogen. The authors have recovered over 200 pounds per acre of nitrogen in a grazed plot experiment.

It must be stressed here that this is the nitrogen recovered in the clover-grass forage. If this much nitrogen were to be recovered in an all grass pasture then, based on current average experience, approximately twice this much nitrogen from a commercial source would have to be applied to the soil. Too often the value of nitrogen recovered from a legume-grass pasture is compared to the cost of an equivalent quantity of nitrogen applied to a grass pasture. Actually it will require nearly twice as much fertilizer nitrogen to obtain the recovery equivalent to that found in the legume-grass pasture. Proper consideration of this point alone will justify considerably more time and effort in the establishment, maintenance and management of legume-grass pastures.

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SOUTHWEST FLORIDA WATER MANAGEMENT DISTRICT

John W. Wakefield, *Presiding*

Factors Involved in Planning for the Management of Water Resources in Southwest Florida

JOHN W. WAKEFIELD[1] AND DONALD P. SCHIESSWOHL[2]

From the Suwannee River on the north to Charlotte Harbor on the south and from the Gulf of Mexico on the west to the outskirts of Orlando on the east is an area of approximately 15,000 square miles in west-central Florida known as Southwest Florida (Figure 1). Here live, work and play one and a half million people in some 18 counties. Economic heart of this area is the growing metropolitan complex of Tampa-St. Petersburg, acknowledged as the fastest growing industrial and business sector of this state. Conservative population forecasts predict an estimated 2½ million people in the area by 1970 and 5½ million people by the year 2000.

Basically Southwest Florida has an agricultural economy, although an industrial climate prevails in the Tampa Bay area. From this changing land and water use stems the water management problems of the area.

It is necessary to touch lightly on some of the basic water resource characteristics of the area in order to understand the problems that are involved. In peninsular Florida, we have quite a number of streams, but they are relatively short and have small drainage areas. These streams are also very flat, having gradients which average approximately one foot per mile.

Now the way nature took care of our surface water problems in the past, and the way she is still doing it to a large extent today, is when the heavy rains come, and we know they are coming, the water would rise a few feet and spread over huge areas in the swamps and surrounding the lakes and streams. It would then gradually drain off through the relatively small, meandering, flat gradient streams which generally were choked with vegetation. There was no need for very large streams.

However, as you and I know, anyone owning property doesn't want water standing on it for months on end. Accordingly, man has gone to work

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to undo the workings of nature. Every time we get a flood, it is only a short time after the land begins to dry off that farmers and others are out ditching and diking in order to remove future waters faster or to prevent them from flooding shallow marsh areas. The result is faster runoff and flooding downstream. In retaliation, the downstream landowner must dig bigger ditches and canals thus speeding the water on its way. So, first we have floods and then over-drainage.

To make the situation more complex, the general rainfall pattern in Florida does not provide for uniform distribution throughout the year. Although there is plenty of rain, about two-thirds of the annual precipitation falls during a period of four months in the summer and fall. For the rest of the year we have to make do with what is left. In addition to this, there are dry and wet years; thus a lack of uniform distribution.

The problems we are facing are similar to the ones we have faced and are continuing to face in the Central and Southern Florida Flood Control District and which we will face in other areas of the state. That is, to replace the natural storage which nature gave us in the form of large expansion areas with artificial storage in limited areas, but storage at greater depths. It is hoped that in this way we can cultivate the land at the same time we will have the necessary water for dry periods.

However, the problem of providing storage is not easy of solution with the type of topography we have in Florida. We do not have any Boulder Dam sites where we can impound the water to great depths. Accordingly, we must resort to the construction of reservoirs similar to those undertaken in the Central and Southern Florida Flood Control District whereby encircling dikes have permitted the district to create water conservation areas. Into these areas water can be pumped in wet weather and withdrawn in dry weather. The significant thing is that we have lots of water storage areas, if we want to utilize the expansion areas which surround every lake and every swamp and every stream in the state. But if we do that we are going to lose a lot of land that we would otherwise be able to use.

The problems of the area, although not fully recognized, were perceived by men of vision in the mid-1950's. As a result, the Legislature, prodded by several years of dry weather, authorized the creation of a number of local water conservation authorities. Among the several created during this period in the Southwest Florida area were the Lake Apopka Recreation and Water Conservation and Control Authority, the Oklawaha Basin Recreation and Water Conservation and Control Authority, the Sumter County Recreation and Water Conservation and Control Authority, the Tsala Apopka Basin Recreation and Water Conservation and Control Authority, and the Peace River Valley Water Conservation and Drainage Authority. These authorities, some of them more active than others, studied their problems and endeavored to arouse public support. In several instances, water conservation control structures were constructed, particularly in the Oklawaha River Basin.

Shortly after the Department of Water Resources (now the Division of Water Resources and Conservation) was created by the 1957 Legislature, the Department in its functional cooperation with local water management authorities organized and sponsored a cooperative study of what is known as the Green Swamp area of Central Florida. This 800-square mile area located east of Dade City comprises a marshy upland of sloughs and ridges which is the headwaters of the principal streams of peninsular Florida, the Oklawaha, Hillsborough, Withlacoochee and Peace. From the data gath-

ered it is also the principal recharge area of the ground-water resources of the peninsula.

This cooperative study, undertaken by the Department of Water Resources, the Florida Geological Survey and the U. S. Geological Survey, was in progress at the time of the 1960 floods. The unusually heavy rainfalls and accompanying floods prompted the department, in cooperation with local interests, to petition the State Cabinet for emergency funds with which to undertake certain water relief studies in the Southwest Florida area. Basis for this request was the initial work that was being undertaken in the Green Swamp study. Based on this preliminary information, the Department awarded contracts to several consulting engineers to expedite water control studies of a number of key areas in the basins of the Hillsborough, Withlacoochee and Oklawaha rivers. The Peace River basin, in the capable hands of the Peace River Authority, was considered adequately covered.

The high-water stages and floods which persisted through most of 1959 and almost all of 1960 provided the stimulus to local interests to come to grips with the problem. Conservative estimates of the flood damage in the area during 1960 exceed 50 million dollars. Particularly hard hit was the Tampa metropolitan area where damage amounted into the millions of dollars.

It appears that effective water legislation in Florida needs to be passed either in a period of severe flooding or in a period of widespread drought. Without a presently existing emergency the citizens seem to forget the urgency and need for cooperative action. As a result of the disastrous floods, legislative and county leaders in the affected area organized a steering committee to explore ways to prevent future flood damage and also conserve water.

The water resources development of Southwest Florida is a complex problem. Basically the area must organize its local resources to work with state and federal agencies. Without a responsible agency, specifically authorized by the Legislature, state and federal governments are unable to expend funds. Furthermore, once works are built, they must be intelligently operated. Thus, an operating agency is imperative.

What then was to be the approach of the people? What could be a possible solution? Based on the preliminary information developed from the proceeding studies, the avenue of solution to the major problems in the Southwest Florida area appeared to lie in controlled storage coupled with sufficient discharge capacity in the waterways to handle flood flows. Adequate water management works would be needed to permit selective discharge from the storage sites. For example, in the Green Swamp area, excess water could be discharged from a single storage area into any one of the four major streams.

As a result of several meetings, the steering committee proposed that legislation be introduced in the 1961 Florida Legislature to create the Southwest Florida Water Management District. This district would be unique for a flood control district in that water management would be the principal theme. Powers of the district would include those to plan design, construct, operate and maintain water management works. The general powers of taxation and eminent domain would be required. Cooperative work with local, state and federal agencies could thus be undertaken.

Contributions were solicited from each of the several counties to finance

continuation of the Green Swamp hydrologic studies in cooperation with the state and federal water resources agencies and to finance certain organizational efforts of the steering committee. Each of the member counties of the group were represented on an overall committee. Throughout all of the organizational activities, the Department of Water Resources carried on continuous liaison with the steering committee and encouraged support of its activities. Through the efforts of the Department, the committee's endeavors materialized into a concerted effort to improve the water resources of the area.

Two particular problems confronted the drafters of the legislation to create a water management district. First, the law needed to be flexible enough to serve the needs of cooperative federal, state and local projects while still being applicable to purely local works. Second, provisions would have to be made for financing of both district and local works on an equitable tax basis.

Two of the principal philosophies of the Division of Water Resources and Conservation have been that the regulating authority of an area's surface water should be based on river basin not political boundaries, and that water resources should be developed by the smallest agency that can finance and operate the desired works efficiently.

In order to satisfy these philosophies the proposed legislation provided for the creation of a water management district with six river basin or watershed boards (Figure 1). The six basins are: Hillsborough, Withlacoochee, Oklawaha, Peace, Anclote and Pithlachascootee, and Waccasassa-Suwannee. District affairs would be managed by a 9-member governing board. Overall guiding policy and planning of all the water management works would be provided by the district board. Large works which would benefit more than one river basin would be financed by the district. The Green Swamp is defined separately from the river basins because of its overall influence on the several river basins. It was placed directly under the district board.

It was proposed that each of the several river basins would have a river basin board. These boards would be made up of a minimum of three members and would provide for representation from each county or part of a county included in the basin. The boards would not do any actual planning or construction but would serve as the local representation for the river basins. Chairmen of the river basin boards would sit on the district governing board.

With this arrangement the two philosophies of the department were reasonably fulfilled. Representation was brought down to the county level, and at the same time, the watershed basin was a hydrologic unit. It might be mentioned here, however, that in actual practice political boundaries did come into play and a number of the watershed basins have boundaries which do not exactly follow the hydrologic boundary. With local representation provided by the representative from each county, the voice of the local people can be heard and carried to the district board level. Thus, the district would be responsive to the grass roots. The planning of basin works, however, would fall into the pattern of the district master plan so that there would be continuity and overall coordination of the district's projects.

The problem of equitable financing of the projects was one which required considerable ingenuity of solution. The more wealthy counties objected to carrying the major share of the cost of basin and district works.

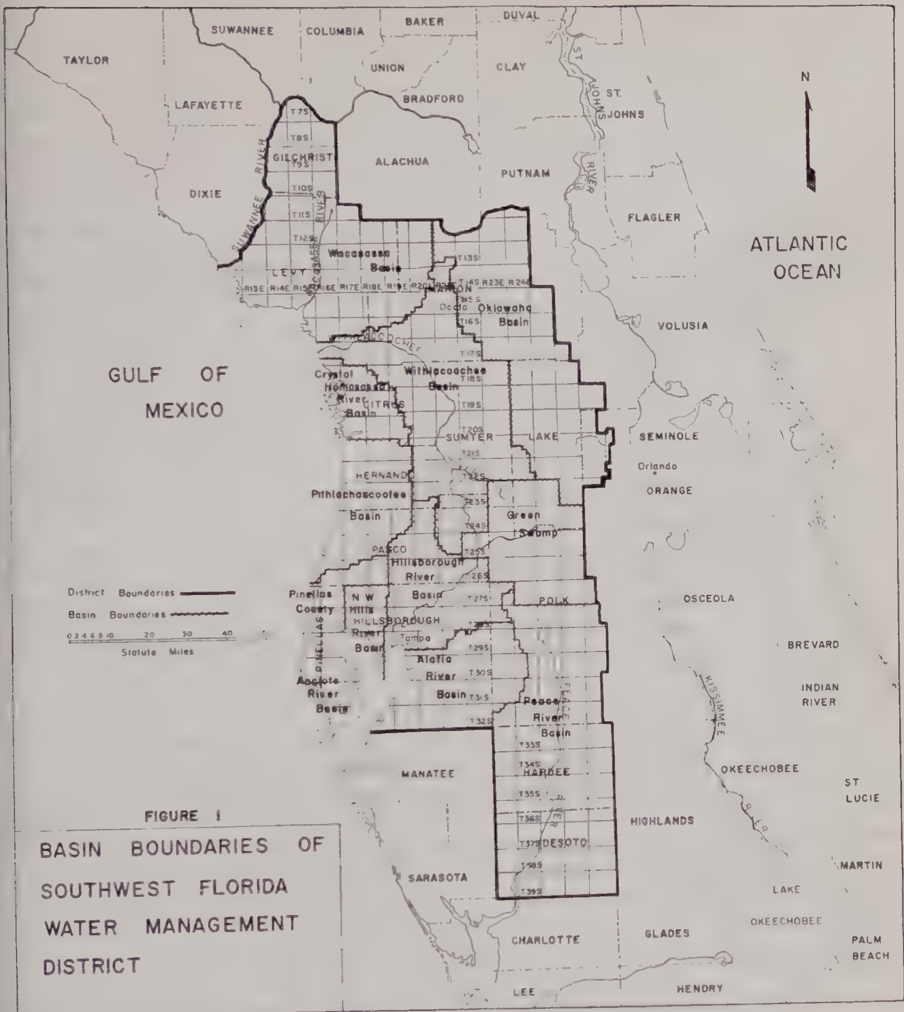

Fig. 1

An inovation was developed which may prove to be of outstanding importance. This is an ad valorem taxing device which adjusts for changes in level of assessment. Existing statutes require the State Railroad Assessment Board to publish the average level of assessment for each county in the state. Since a number of counties are reevaluating their assessments, there is a marked increase in the level of assessment from year to year. It appeared obvious that if a district-wide ad valorem tax rate were applied, the amount of tax collected in any one county would be proportional to the level of assessment for that particular year. Those counties that had high rates of assessment would contribute considerably more than counties with very low rates of assessment. Under the scheme in the proposed act the tax rate for a given county is based on the ratio of the level of assessment in that county to the average level of assessment in the district. As the county level of assessment changes, so does the tax rate to give pro-

portionally the same amount of tax each year as long as the true value of property in the county does not change. Each county, therefore, has a different tax rate to provide its share of the total funds needed by the district.

Two taxes are authorized. A district-wide tax to finance district works and works in the Green Swamp area and a basin-wide tax. The district tax is limited to a maximum of 3/10 mill and is restricted in the first year of application to 1/10 mill. Money from the basin tax would be used only for basin-wide works. This is the money that the basin board can work with for basin works. The actual handling and financing of the basin works would be done by the district governing board. The basin tax has a provision that it shall not exceed one mill.

After numerous consultations with county and political leaders the proposed act was considered satisfactory to the majority of the counties. Through the cooperation and interest of legislative leaders, the water resource bill creating the Southwest Florida Water Management District was finally enacted by the 1961 Legislature. This legislation has the features outlined.

Since each watershed basin is self-supporting, insofar as local funds are concerned, it is possible that work may go on concurrently in more than one watershed of the district. Availability of state and federal funds will become a factor where general, rather than local, distribution of benefits indicates the propriety of cooperative projects. The ability of the district to undertake multiple-purpose projects will have a definite limit. Much preliminary planning can, however, be undertaken by the district and watershed basin boards.

Small meandering streams of flat gradient, continued encroachment upon marginal and marsh lands by urban and agricultural development, and a hefty expansion in population and business and industrial development in the area, together with a capricious nature which in two years dumps twice the normal amount of water upon the area, were factors which prompted planning for the management of the water resources of southwest Florida. With the Division of Water Resources and Conservation serving as the catalyst, the local people organized themselves into a body politic with which to deal more effectively with their water resources problems. Time will tell how effective this fledgling organization will develop.

The Relationship of the Natural Water Systems of Green Swamp to Water Management in That Area[1]

G. E. FERGUSON[2]

INTRODUCTION

The storm waters of Green Swamp in central Florida have attracted wide attention during the past few years. The manner in which these waters store in and move from the swamp during periods of general flooding are reported to aggravate the inundation of croplands well beyond the boundaries of the swamp. Water-control engineers are now engaged in the planning of remedial works.

However, the natural systems of storage and movement of the waters of Green Swamp are so complex and so obviously a vital part of the water resources of Florida that an intensive hydrologic study is being made. The findings from this study will be incorporated into the water-control planning so that natural beneficial features of water will not be destroyed.

Although the hydrologic investigation is only in its early stages, it does provide a general knowledge of the manner in which water occurs, moves within and is utilized outside of Green Swamp. A summarization of the findings is appropriate. Public attitude regarding Green Swamp is in a formative stage and it should be built upon all available water facts.

Green Swamp is in the interior of and about half way down the Florida peninsula (Fig. 1). It is closer to the Gulf of Mexico than to the Atlantic Ocean. The boundaries of the Green Swamp area are somewhat arbitrary and may differ according to individual interpretation. However, as designated for this investigation, Green Swamp lies north of Lakeland, south of Groveland, east of Dade City and west of a line between Clermont and Haines City.

Despite its name the area is not a continuous swamp but is a composite of many swamps, sloughs, and sinkholes that are distributed fairly uniformly. Interspersed among the swamps are ridges, hills, and flatlands that are several feet higher than the surrounding marsh.

1Publication authorized by the Director, U.S. Geological Survey.

2Division Hydrologist, U. S. Geological Survey, Arlington, Va. Mr. Ferguson has spent essentially his entire career in the field of scientific water resources investigations in the U. S. Geological Survey. In his early years he measured and studied stream runoff on the lower Rio Grande (1928-31), Hawaii (1931-37) and in the middle Atlantic States (1938-40). He was in charge of surface water investigations in Florida during 1941-46. In 1947, he was transferred to the Washington, D. C. headquarters to work on reorganization and later to coordinate the Nationwide programming of water resources. Since 1957, he has been directing the planning of cooperative water studies for Atlantic coastal States. He is a past National Director of American Water Works Association, and has held numerous local and other offices in that Association. He is also a member of American Geophysical Union, American Association of Civil Engineers and the Cosmos Club. Mr. Ferguson is co-author of several water resources reports including "Springs of Florida" (publ. by Florida Geol. Survey) and "Water Resources of Southeastern Florida" (U. S. G. S. Water Supply Paper). He developed (1940) the nationally and extensively used pipe-type crest stage gage for river flood studies.

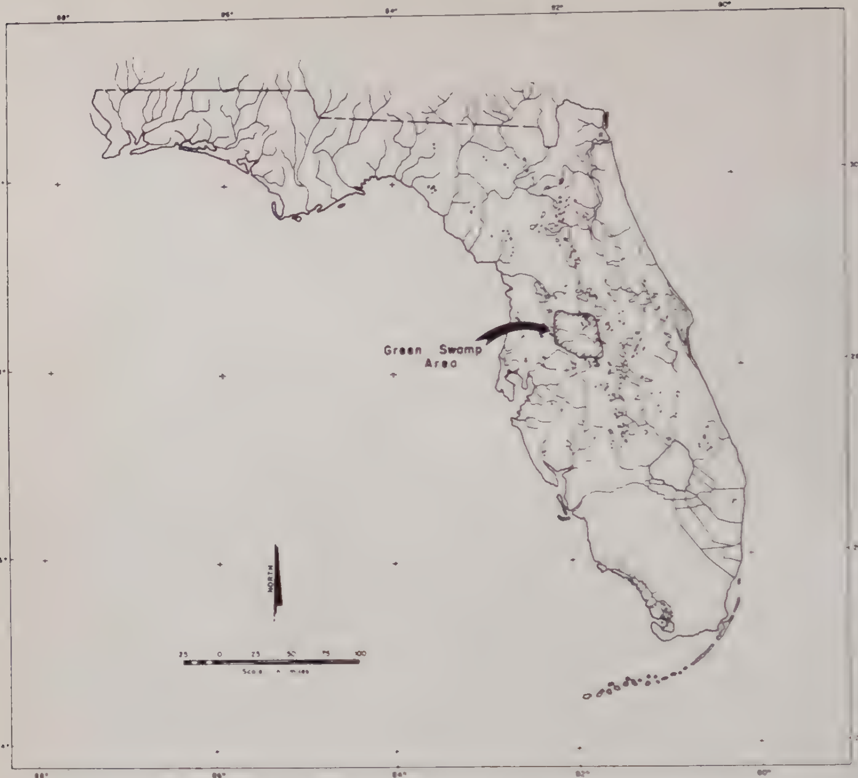

Fig. 1.—General location of Green Swamp area.

Green Swamp largely is privately owned, is sparsely populated and economically, is currently marginal. It has produced some timber and supported limited mining of phosphate and sand. The higher sand ridges and hills are planted in citrus groves and the flatlands are used for cattle raising.

The extremely dry years of 1954-56 invited the utilization of more of the low lands for agriculture. The record-breaking wet year of 1959 caused flooding of great magnitude. High waters of Green Swamp are reported to have contributed substantially to the flood problems over a considerable area beyond the boundaries of the swamp (U. S. Congress, 1959, p. 2753-7). The damage caused by the 1959 and 1960 floods was the primary motivation for the present study and planning activities at State and Federal levels.

To hydrologists and others concerned directly with water problems, Green Swamp is a unique area. It belongs to no one river basin. The natural divides between the several river systems within the swamp are low and in places permit direction of drainage to be determined by storm centers. In the cataloging of Florida river basins by the State, Green Swamp is considered a separate entity (Wakefield, 1959). The swamp has a special significance also to the ground-water supplies of central Florida. It contains the summit (Stringfield, 1936) of that enormous body of underground water that is one of Florida's major natural assets. The movement of the ground waters of Green Swamp is as diverse as its stream waters.

Although the discharge of the major streams leading from Green Swamp has been measured at downstream points for many years, no study of the waters within the swamp was made until 1958. In July of that year the Federal Geological Survey, in cooperation with the Florida Geological Survey and the Florida Department of Water Resources, began such a hydrologic investigation. Specific boundaries of the project were drawn and include an area roughly quadrilateral in shape and nearly 900 square miles in size.

An interim report by Pride, Meyer and Cherry (1961) on findings from this investigation has been published recently as Florida Geological Survey Information Circular 26 and is recommended to those who feel an interest or a responsibility in the water resources of central Florida. Much of the following information has been condensed from the circular. The study is continuing and the additional findings will be made available as expeditiously as possible.

The problem of Green Swamp is a matter of topography as well as water. The relatively low topographic relief affords great natural water storage and reduces the rate of movement of the waters. Accurate large-scale maps are thus an aid to understanding the area and its problems.

The most detailed maps of Green Swamp are the quadrangle sheets prepared by the Federal Geological Survey on a scale of one inch equals 2,000 feet. Some twenty of these 7.5 minute series quads cover the area. Seventeen of these are already available in published or preliminary form. Mapping is in progress on the other three, all of which should be published by 1964.

THE WATER SUPPLY

Green Swamp's only supply of water comes from the atmosphere as rainfall. The atmosphere is a claimant for, as well as, a supplier of water. The forces of evaporation and transpiration are constantly at work, and in the warm Florida climate these water losses are substantial.

The annual rainfall averages nearly 53 inches. More than half of this usually falls in the four summer months and only about one-sixth in the four winter months. The water supply in an average year is generally lowest in May, just preceding the summer rainfall.

The annual rainfall during the period 1931 to 1960 has exceeded the average for those years slightly more than half that time and ranged from nearly 40 percent above average to 28 percent below. Very wet years were nearly always separated by near normal years. The wet years of 1959 and 1960 are thus unusual. But dry years often were consecutive, and this extreme condition challenges the best designers of water-control works. The outstanding drought during the 30-year period was caused by three consecutive years of low rainfall beginning in 1954. In 1954 the deficiency was about 28 percent, in 1955 it was about 18 percent and in 1956, about 12 percent.

The portion of this water that is returned to the atmosphere varies greatly depending upon the degree to which the water is exposed to the forces of evaporation and transpiration. The opportunity for evaporation is greatest from the warm exposed waters lying in shallow swamps. The loss from these swamps may exceed the nearly 50-inch annual rate reported (Kohler, 1959) for lakes. Aquatic plants growing out of the edges of swamps have high rates of transpiration. Other smaller losses occur directly from the ground surface and from the leaves of all vegetation.

It is practical to measure such atmospheric losses from entire basins only through indirect methods. The mean annual temperature of Green Swamp is 72°F. The annual water loss for this mean annual temperature has been reported (Langbein, 1949) as 48 inches. This is likely conservative as applied to Green Swamp with its many swamps and sluggish runoff.

It is interesting to compare the average annual rainfall of about 43 inches during the three-year drought of 1954-56 with these higher evaporation rates. The actual annual evaporation is dependent, of course, upon the degree of exposure of the water to evaporation. This evaporation opportunity is reduced in dry years, but the forces of evaporation and transpiration are major factors in the control and conservation of waters in all years. The water supply available for the beneficial uses of man is thus the difference between rainfall and evapotranspiration.

THE NATURAL WATER SYSTEMS

The waters of Green Swamp not returned to the atmosphere either flow out of the area through surface channels or percolate downward into the natural underground reservoirs and then move laterally apparently in all directions. The movement of the water below the surface is considerably more complex than in most basins. This is because of the relatively flat topography and the interrelation of the various underlying water bearing formations.

Surface outflow and downward percolation take place concurrently. They are more rapid during wet periods and diminish as the water supply decreases. However, some surface outflow continues throughout the dry periods. Ground-water recharge through the deeper swamps and lakes apparently is also continuous.

During and following heavy rainfall, the series of swamps, lakes and sinkholes become continuous water channels which are the headwaters of five stream systems (Fig. 2). These are listed by Pride (1961) in order of proportion of the area drained as: Withlacoochee River, Little Withlacoochee River, Palatlakaha Creek, Hillsborough River and Reedy Creek. In addition to these, the present headwaters of the Peace River lie adjacent to the southern boundary of the Green Swamp project area. In its natural state Green Swamp is believed (Johnson, 1961) to have contributed to the flow of Peace River.

Drainage is to the Gulf of Mexico except Palatlakaha Creek and Reedy Creek which flow into St. Johns and Kissimmee Rivers, respectively. Flow patterns may vary with individual storms. Local storm centers may "mound" waters and cause flow over low normal drainage divides.

Man has already altered the pattern of surface flows by means of drainage canals and levees. These works appear to have changed the proportion of water removed by the several river systems. They have undoubtedly speeded up the rates of storm discharge and have lowered the water levels of the swamps following the storms. Detailed flow patterns cannot be determined accurately because stream measurements of swamp outflow began only recently. Additional local measurements will define better the rainfall-evapotranspiration-runoff relationships.

Water percolating into the ground reaches and recharges two distinct types of ground water reservoirs, one lying above the other and separated in most places by relatively tight beds of clay. The upper reservoir is in a nonartesian aquifer composed largely of sand. It lies on the surface and is

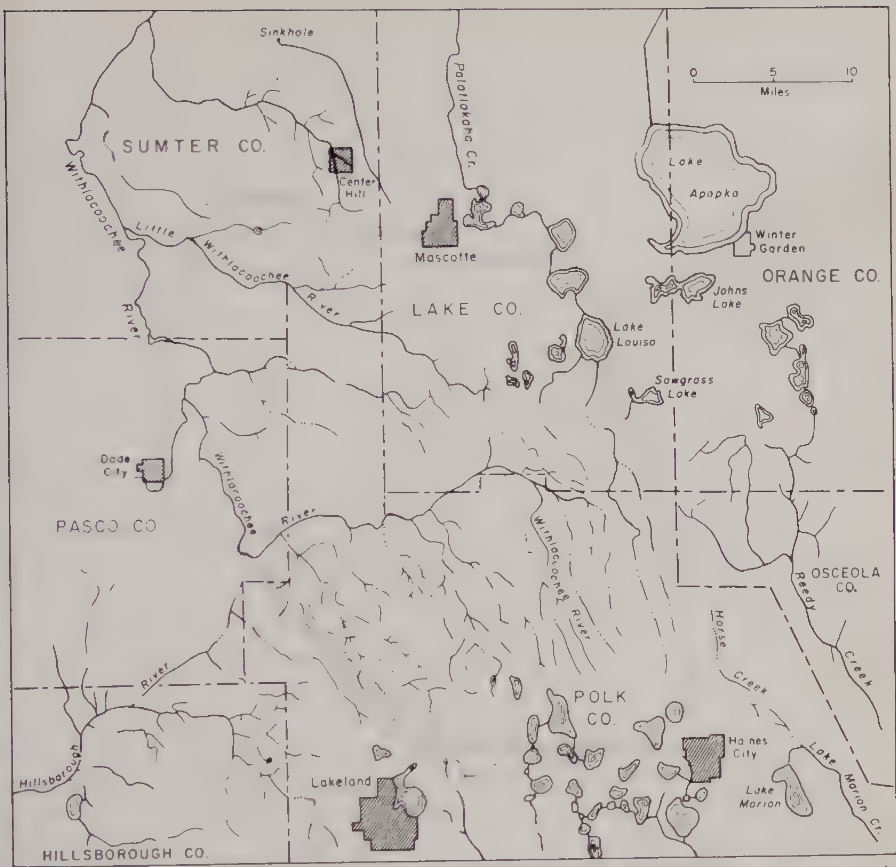

Fig. 2.—The Green Swamp serves as headwater area for five stream systems in Central Florida.

more than 100 feet thick in the eastern part of Green Swamp but is thin or absent in the western part.

The water table in this upper reservoir rises when recharge from percolating rainfall exceeds the outflow and declines when outflow exceeds the recharge. Some of the water in this aquifer moves downgradient into stream channels and lakes. Some percolates downward into the lower reservoir and a negligible amount is removed by pumping. Evaporation and transpiration losses are appreciable where the water table is at or near the surface.

The lower reservoir is a part of the Floridan aquifer which is a widespread and major source of ground water in Florida (Parker, 1955). This aquifer occurs at depth in the eastern part of Green Swamp but gradually rises to points at or near the surface in the western part. Where the water is confined ,it is under artesian head and in Green Swamp the head is sufficiently high to form a ground water mound in the Floridan aquifer. Green Swamp may be the most important recharge area of this aquifer.

Water from Green Swamp moves downgradient and in all directions through the Floridan aquifer. The top of the Floridan aquifer lies at the surface of the ground in western portions of Green Swamp and there is

recharged directly by rainfall and from bodies of surface water. Water moves in the artesian aquifer in ways that do not differ greatly from the nonartesian aquifer. Seepage may be upward into the nonartesian aquifer as well as laterally to springs and surface-drainage sources. Yields of wells in the Floridan aquifer are notably large, and great quantities of water are removed for industrial and municipal purposes in many parts of the State.

The quality of the Green Swamp waters permits their use for all usual purposes. The mineral content of the waters leaving the Swamp as stream flow is low. That of the artesian waters is usually higher because of its contact with the soluble rocks composing the aquifer. The stream waters flowing from the swamp are highly colored but have negligible sediment and low turbidity.

As the foregoing description indicates, hydrologic studies thus far reveal primarily the general nature of the natural water systems of Green Swamp. As the investigation proceeds the patterns of recharge and discharge will become better defined. A specific effort is being made to determine the functions of the sinkhole lakes in the recharge processes. Some Florida lakes are effective recharge channels to ground-water aquifers but others have relatively tight beds. Methodology by which the answer may be revealed is not lacking. Careful and accurate observation of static water levels throughout a variety of water-supply conditions is a basic part of the procedure. This requires not only considerable effort but an extended period of time.

GREEN SWAMP'S FUTURE

One can view this "birthplace" of several rivers and summit of an aquifer with considerable sentiment. To some it is a relatively virgin area deserving of protection as a natural preserve and watershed. To others it is a source of recurring flood-water problems which damage agricultural pursuits. Planners will undoubtedly strive to make the best reconciliation of a variety of possible "single-purpose" plans. The day of the relatively simple and direct single-purpose plan is over. Comprehensive, multipurpose planning with all its complexities is here to stay and a challenge to the best planner.

The significance of Green Swamp to the water economy of central Florida likely will be better appreciated by our great grandchildren and their great grandchildren. As population grows, our needs for water increase. As the aesthetic and recreational potential of each lake and stream is approached, man will be ever more sensitive to water levels, lake levels and stream flows. Flood hazards can be reduced and water stored rather readily through engineering science. Alert water management can do much to maintain desirable water levels and flows during reasonably dry periods. The conservation of adequate water for all needs during sustained droughts of two and three years, however, may remain a major challenge.

ACKNOWLEDGMENT

The original tracings of the two figures included in this paper were borrowed from A. O. Patterson, District Engineer, U. S. Geological Survey, Ocala, Florida.

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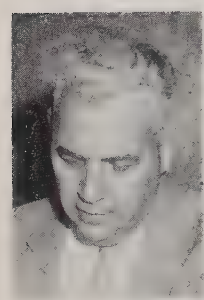
The Effects of Water Control in the Green Swamp on the Management of Water Resources in the Peace River Basin

LAMAR JOHNSON[1]



The effects of water control in the Green Swamp area upon the management of water resources in the Peace River Basin are difficult to evaluate accurately because of the close relationship of surface water and ground water in much of the Green Swamp area and in the headwaters of the Peace River. A general understanding and recognition of this relationship is our only hope that we can provide the tools that are necessary to make this relationship work to the maximum benefit of water utilization within the Peace River Basin and beyond.

The Peace River is the largest of the four major streams flowing out of Green Swamp. Most of Charlotte, DeSoto, Hardee and Polk counties are within the Peace River Basin. Its present restricted drainage area is about 2,180 square miles. I emphasize the use of the term "restricted" in connection with its drainage area that in primeval times included not less than 20 square miles of what we now call Green Swamp. The natural drainage area of Peace River was reduced by the construction of the A.C.L. Railroad between Lake Alfred and Haines City which provided only two 48", high elevation culverts to serve this Green Swamp connection. This restriction of the natural drainage area has contributed to the flooding in Withlacoochee and Oklawaha Basins, particularly in heavy rainfall years.

The establishment of the proposed impoundment area on the piezometric high of Green Swamp, between Polk City and Haines City, will restore and exceed the once natural drainage area of Peace River. As the Peace River has the highest rate of runoff of any major stream of peninsular Florida, and paradoxically less damaging floods than the other three rivers having their sources in Green Swamp, the control of the approximately 72 square miles of the proposed high impoundment drainage area through the Peace River system is logical. Relief of the Withlacoochee and Oklawaha Rivers from the control discharge of the impoundment area will contribute to solution of the flood control problem in those basins.

There has been limited criticism from those who do not understand the purpose of the impoundment area on the piezometric high of the

[1]Consulting Engineer, Lake Wales, Florida.

[1]Lamar was born somewhere in Florida early in the present century and, after a due exposure to the State educational system, joined the reclamation work in the Everglades during the deep travails of its early development. After many years of good and faithful service and during the interim of destroying the old Everglades Drainage District and forming the new Central and Southern Florida Flood Control District, he spent several years in Virginia only to return to service in the new District for a number of years. More recently he has moved out of his favorite swamp to the higher land of Lake Wales from which vantage point, and with his feet now dry most of the time, he is laboring mightily in the interest of a "new look," from the water conservation standpoint, for that important area in Central Florida known as "Green Swamp."

Floridan aquifer that it will not be an efficient reservoir. Reservoir storage, as such, is not the objective of creating and operating this impoundment area. The primary objective here is to retard runoff and provide longer opportunity for the impounded water to percolate downward into the ground water and into the Floridan aquifer. The maintenance of the existing piezometric high is of great importance to Central Florida, and particularly to the Peace River Basin where much of the water use is from ground water sources.

The piezometric surface elevation of the Floridan aquifer in the upper Peace River Basin has fallen 10 feet generally and 20 feet in some locations during the past 10 years. This decrease has been caused primarily by greater industrial and agricultural use. Contributing to this loss has been the general reduction of surface storage by overdrainage and reduction in lake stages. An increasing contributing factor is the open pit mining of phosphates below the piezometric elevation, disturbing the blanketing effect of the natural surficial materials. The objective of the creation of the proposed impoundment area on the piezometric high of Green Swamp has application in the natural lakes and phosphate excavations of the upper Peace River Basin.

The Peace River is capable of being improved to transport surface water supplies to the potable water deficient counties of Charlotte, Sarasota and Manatee. The rapid development of these coastal counties is already straining their local supply of surface and shallow ground water. As the deep ground water supply is too highly mineralized for most uses, these counties must look to some long-range supplemental supply. The upper Peace River Basin is such a potential source of supply and the Peace River can be improved to transport this supply.

The Peace River Valley Water Conservation and Drainage District has prepared a plan of improvement for Peace River proposing the canalization of the natural stream with nine controls. This plan cannot be economically justified at this time as there is little development in the flood plain contributing to flood damages that justify the improvement. It is entirely possible that by the time improvement can be justified that it will be on a basis of water supply instead of on the normal basis of flood control and navigation. It is also possible that by that time the desirable plan for the river may be a series of dams with spillways that would provide more storage in the flood plain of the river than the District's plan provides.

No plan for river improvement to transport water can be justified unless there is available water to be transported. The opportunities for storage in the upper Peace River Basin are above average. The problem is to plan today to utilize this potential storage tomorrow.

In the upper Peace River Basin there are more than 50 square miles of natural lakes that can be controlled to conserve water and to some degree provide a supply for downstream distribution. There is today an equal area of phosphate mining excavations and this area is increasing by several square miles each year. Much of this excavated area can be used for water storage at low unit cost. Eventually, a large part of the River Basin west of the river in Polk and Hardee Counties will be mined and important storage areas will result. There are also additional storage sites available in the larger tributaries of the river and in the river flood plain itself. The possibilities for useable storage in the headwaters of the Peace River are greater than for any coastal river between the Caloosahatchee and the Suwannee.

The conservation and management of water storage in the Green Swamp impoundment area, in the lakes of the upper basin, and in the increasing areas of abandoned phosphate excavations can provide many benefits:

First, there is the opportunity to prevent runoff by storage and thereby decrease flooding problems.

Second, in preventing wasteful runoff and increasing storage, additional supplies for beneficial use are available.

Third, controlled storage in the natural lakes and abandoned phosphate excavations, to an elevation equal to, or above, the elevation of the piezometric surface of the Floridan aquifer, will reverse the present negative effect resulting from the lesser control.

Fourth, a better control of stages in the lakes, phosphate excavations, and channels will result in a more stabilized ground water table generally which will prove beneficial to agriculture.

Fifth, the management of waters in the storage areas and control channels will provide additional recreational opportunities, as well as minor benefits such as amelioration of temperatures, betterment of living environment, and fish propagation.

The Peace River Basin does have a pollution problem created by its extensive agricultural and mining industries. The local people and industry are becoming increasingly aware of the problem and the necessity of doing something about it. Progress is being made, and I am confident that the problem will decrease as the demand for useable water increases.

The brightest part of the long-range picture of water conservation and management in the Green Swamp area and in the Peace River Basin is that we are not as late in recognizing the problem and taking steps to provide for the future as we have been in some other areas of Florida. The lands where works will be required are relatively underdeveloped today, although development is beginning. The soils are generally stable and excavation and foundation conditions are favorable to low unit cost construction. The dual possibility of surface storage and sub-surface storage for beneficial use should provide an efficient system for low unit cost water conservation.

The important part of the long-range picture of water conservation and management in the Green Swamp area, as it affects the Peace River Basin, is that the focus of attention upon the importance of Green Swamp to Central Florida will hasten the recognition of the importance of Peace River to a large part of Southwestern Florida. This recognition will not only stress the importance of the natural lakes and streams of the Peace River Basin, but will help us to realize the wonderful opportunity for storage in the abandoned phosphate excavations.

These abandoned excavations could some day collectively form the deepest, most efficient reservoir in Florida.

BANQUET AND BUSINESS MEETING

The Annual Banquet was held in the Hotel Floridan on the evening of November 15. This was immediately followed by an exceedingly interesting address by Dr. George K. Davis, Director of Nuclear Research and Research Professor of Animal Nutrition, University of Florida, on "Fundamental Research and Practical Agriculture," which was followed by a film entitled "Nuclear Research in Florida."

Following the address and film, the Annual Business Meeting was called to order by President W. H. Chapman. The usual routine of business was transacted. This included reports of committees and of the Secretary-Treasurer, particularly as the latter pertained to membership and the financial status of the organization.

MEMBERSHIP

The trend in membership is vividly shown in the following table in which the members for 1960 are also listed by category and by geographical distribution for comparison with 1961.

GEOGRAPHICAL DISTRIBUTION OF MEMBERSHIP BY CATEGORY

	Annual		Sustaining		Honorary Life		Total	
	1960	1961	1960	1961	1960	1961	1960	1961
Florida	520	486	78	76	2	3	600	565
U.S. other than Florida	166	145	38	33	14	15	218	193
Caribbean	77	65	10	8	3	1	90	74
Foreign	39	43	5	4	1	1	45	48
Total	802	739	131	121	20	20	953	880

In a brief oral report on membership, reference was made to the stimulation afforded by correspondence on this subject particularly from members in distant parts of the world as, for instance, Sir. John Russell, former Director of the famous Rothamsted Experiment Station, when he writes at age 86 of his regret that the distance prevents his attendance upon the meetings and how he would have liked in particular to sit in on the Nitrogen Symposium: or when Mr. R. A. Colyer down in Sydney, Australia, upon returning from a world-wide trip and finding our little "dues due" dun, hauled off and sent us, up and over, the $21.00 in U. S. Currency which he just happened to have left over. There are few who can realize what a struggle it was for the Secretary not to convert him to a Sustaining Member right then and there. However, the record shows him still in the Regular Member column with annual dues paid to and thru 1968!

REPORT OF TREASURER

Statement of Receipts and Disbursements
Jan. 1, 1961 thru Dec. 31, 1961*

Cash in bank Jan. 1, 1961		
Florida National Bank	1,252.29	
Everglades Federal Savings & Loan Co.	4,157.31	
		5,409.60
RECEIPTS:		
Regular dues collected	2,115.00	
Sustaining dues collected	2,350.00	
Proceedings sold	239.00	
Postage refunds	5.04	
Donations	5.00	
Dividends for savings account	171.63	
Registration at annual meeting	254.00	
Banquet tickets sold at annual meeting	210.00	
		5,349.67
Total monies to be accounted for		$10,759.27
DISBURSEMENTS:		
Office supplies	69.75	
Postage	217.00	
Publications (Balance on Vol. 19)	2,401.52	
(partial payment on Vol. 20)	3,747.57	
Expenses of 20th annual meeting (Bal.)	72.61	
21st annual meeting	311.68	
Binding office copy of Proceedings	6.18	
Travel — R.V.A.	7.95	
Bank service charges	.67	
Check returned	3.00	
		6,837.93
Cash in banks Dec. 31, 1961		
Florida National Bank	792.40	
Everglades Federal Sav. & Loan Co.	3,128.94	
		3,921.34
Total monies accounted for		$10,759.27

*As in the past the calendar year is used as a basis of reporting because of the several conveniences afforded in doing so that already have been discussed in detail.

PUBLICATION

Due to the untimely death of Dr. Steiner before he could complete his contribution to the Nematode Symposium of 1959 the Society deferred to the University of Puerto Rico, by whom he had been employed since his retirement from USDA in Washington, with respect to publication of the material he had brought together for the above purpose. Inasmuch as the University expressed a desire to edit and publish the whole of his accumu-

lated data in the field of tropical nematology this left us without what we had come to regard as the key paper in the symposium. In consequence of this the Executive Committee decided not to reissue as a reprint those papers of the symposium that already had been published in Proceedings Volume 19.

REPORT OF COMMITTEES

NOMINATING COMMITTEE

The Nominating Committee was appointed well in advance of the business meeting by President Chapman. It was made up of Dr. C. E. Hutton, Dr. W. L. Pritchett and Dr. E. S. Horner, with the latter acting as Chairman, and charged with presenting at the proper time one or more candidates for the office of Vice President, the only elective position to be filled each year. Upon call for the report of the committee the chairman offered in nomination only the name of Dr. H. C. Harris. There being no further nominations from the floor the chairman of the committee moved the nominations be closed and the Secretary instructed to record the vote for Dr. Harris as unanimous. In consequence of several prompt seconds and no questions to the motion, Dr. Harris became the new Vice President of the Society and, simultaneously, by force of precedent, the Chairman of the Program Committee for 1962.

RESOLUTIONS COMMITTEE

The Resolution of Sympathy read by the Secretary told of the loss of seven members of the Society during the year, two of them from the Honorary Lifetime group. At the request of the President the reading was followed by a brief period of silence. The names of those included in this list will be found published in proper form on page 307 of this volume.

NOMINATION AND ELECTION OF HONORARY LIFETIME MEMBERS

As a result of the death of two of our Honorary Lifetime Members during the year the chairman asked the secretary to present the names of two long-time members of the Society, both in fact charter members, who had been chosen to take the place of Dr. H. Steiner and Mr. H. G. Clayton. They are, respectively, Dr. H. E. Middleton of Winter Park and Dr. J. R. Neller, of Gainesville. As is customary the picture of each along with a brief biographical sketch is to be found at the front of this volume where the full list of names is published each year.

PASSING OF THE GAVEL

Immediately following the announcement of the names of the new Honorary Lifetime Members the outgoing President, W. H. Chapman, passed the gavel to Dr. W. G. Blue and he by its acceptance became the 22nd President of the Society. At the same time Mr. Chapman, as immediate past president, became a member of the Executive Committee, replacing Mr. J. R. Henderson in that position. Dr. Blue's first and only act before declaring the business meeting closed was to call a meeting of

the Executive Committee to follow immediately. The business meeting was adjourned at 10:45 p.m.

MEETINGS OF THE EXECUTIVE COMMITTEE

The meeting of the Executive Committee was called to order by Chairman Blue immediately following the close of the business session. Only a limited session could be held since the new Vice President could not be present.

The Secretary-Treasurer of the past year was requested to continue in the office following a brief discussion of the need for appointment of an active and responsible Editorial Committee. Appointment of this committee in due course consisted of George D. Thornton as Chairman with E. S. Horner, V. E. Green and Nathan Gammon, chosen for three, two and one year terms of service, respectively.

As usual the place of meeting and subject matter for the program also were discussed briefly but final decision in both matters delayed until later meeting. Likewise the question of so dating the publication of the Proceedings that it could be used as official public reference as to time of appearance of the contained papers, was brought up. Its importance was recognized but full discussion and final decision were delayed until details of procedure could be obtained.

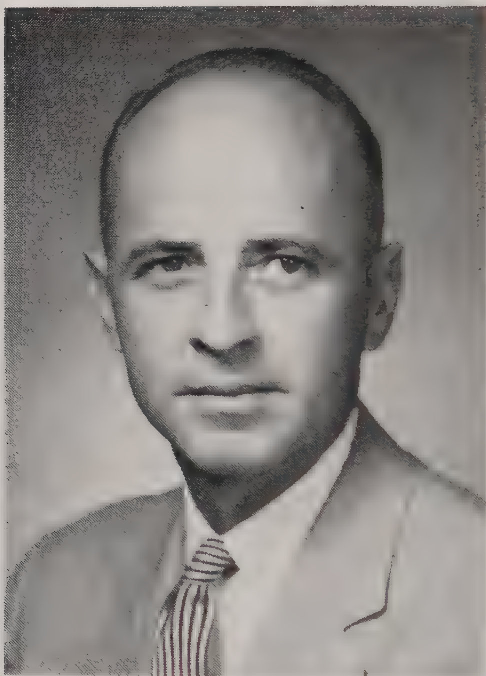
In the course of a later meeting of the Executive Committee in Gainesville on January 19, Hotel Langford in Winter Park was selected for the 22nd annual meeting (1962) and the date set at November 13, 14 and 15. In addition to discussing plans for the program in detail and the issuance of a call for contributed papers by April with a reminder in August of the need to submit title and abstract by September first, decision was taken to set up about a dozen subject matter committees, each of a permanent nature and a chairman whose tenure would be continuing, until relieved. The purposes and coverage of these committees as well as the names of the appointees will be presented at the Winter Park meeting in November.

RESOLUTION OF SYMPATHY

WHEREAS, death has taken from our rolls during the year the following esteemed members of the Society whose sincere and constructive interest in all aspects of the work will make their absence keenly felt for a long time to come,

NOW, THEREFORE, BE IT RESOLVED, that this expression of sorrow over this great loss and of sympathy to the immediate families of the deceased be spread upon the records of this Society and a copy of same be sent to the closest member of the family of each.

Don Butts, Orlando
H. G. Clayton, Gainesville
Karl M. Kaiser, Guatemala
Edward T. Keenan, Frostproof
E. J. Morgan, Pompano Beach
R. Henry Morris, III, Philadelphia, Pa.
G. Steiner, Puerto Rico



W. H. CHAPMAN

OFFICERS OF THE SOCIETY

1961 Retired

W. H. CHAPMAN (Quincy)	President
W. G. BLUE (Gainesville)	Vice President
J. R. HENDERSON (Gainesville)	Past President
R. V. ALLISON (Belle Glade)	Secretary-Treasurer

SUSTAINING MEMBERS

1961

Allied Chemical Corp., Nitrogen Div., 40 Rector St., New York 16, N. Y.
Andrews, Charles O., Jr., 1216 E. Colonial Drive, Orlando
Ariens, Mando S., 109 Calumet St., Brillion, Wisc.
Arvida Greenhouses, Inc., P. O. Drawer 130, Miami 57
Bair, Dr. Roy A., 256 Alhambra Place, West Palm Beach
Baker & Bro. Inc., H. J., Box 1273, Tampa 1
Ball, J. A., Jr., Box 296, Belle Glade
Battaglia, S. C., Box 398, Winter Garden
Bessemer Properties, Inc., 440 N. E. 17th St., Miami
Bobkowicz, Emilian, Canadian Imp. Bk. of Com. Bldg., Montreal, Canada
Bouis, C. M., Florida Fruit Co., Box 438, Leesburg
Bovell, G. L., Box 179, Port-of-Spain, Trinidad, B.W.I.
Burpee Company, W. Atlee, Box 861, Sanford
Burrichter, August, Box 42, Homestead
Butts, H. L., 398 So. Ocean Drive, Boca Raton
Caruso, J. M., 1626 Spring Lake Drive, Orlando
Cary Iron Works, Inc., Box 469, Opelousas, La.
Central & Southern Florida Flood Control District, 901 Evernia, West Palm Beach
Chase, Randall, Box 291, Sanford
Collins, Thomas H., 4426 Bass St., Tampa 10
Cotton Producers Association, Box 2210, Atlanta 1, Ga.
Creech, R. Y., 5790 Estero Blvd., Fort Myers Beach
Cummer Lime and Mfg. Co., Box 536, Ocala
Davison Chemical Corp., Ft. Pierce
Deerfield Groves Co., Wabasso
Denton, Marion G., Marden Mfg. Co., Auburndale
Diamond R. Fertilizer Co., Inc., Box 132, Winter Garden
Diebold, A. Richard, 375 Park Ave., New York 22, N. Y.
Dieseldorff, F. Arturo, Cordeleria "La Rapida," 16 Ave. 9-57, Guatemala, C.A.
Donahue, Edwin L., Box 30, Clifton, N. J.
Duda, A., & Sons, Oviedo
Escagedo, Gregorio, 2215 Arch Creek Drive, North Miami
Everglades Federal Savings & Loan Assn., Box 548, Belle Glade
Florida Farm Bureau Federation, 4350 S. W. 13th St., Gainesville
Florida Flower Assn., Inc., P. O. Box 1569, Ft. Myers
Florida Fruit & Vegetable Assn., Box 6787, Orlando
Florida Nitrogen Co., Box 2619, Tampa
Florida Power and Light Co., Miami
Forman, Dr. Charles R., 3300 N. E. 17th St., Fort Lauderdale
Gehring, Wm., Inc., Rensselaer, Ind.
Geigy Agricultural Chemicals, Box 430, Yonkers, N. Y.
Grace, W. R., & Co., 147 Jefferson Ave., Memphis 3, Tenn.
Graves, J. R., Graves Bros. Co., Wabasso
Greenwood Seed Co., Box 890, Thomasville, Ga.
Griffin, B. H., Jr., Box 127, Frostproof
Griffin, James F., Jr., 79 Harbor Drive, Key Biscayne, Miami 49
Growers Fertilizer Co-op, Lake Alfred
Haines City Citrus Growers Assn., Haines City
Hamilton Growers, Inc., Lake Hamilton
Hatton, Joe, Box 164, Pahokee
Hills, George B., Box 4817, Jacksonville 1
Holland, Frank L., 315 Phillips Prof. Bldg., Winter Haven
Holman, B. T., 180 No. Michigan Ave., Chicago, Ill.
Home Guano Co., Box 577, Dothan, Ala.
Hottenroth, Dr. K., c/o Chemirad Corp., Box 187, East Brunswick, N. J.
Huxtable, Austin, 650 Tweedsmuir Ave., Ottawa, Ontario, Canada
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